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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFGWC/TN-79/003
2. GOVT ACCESSION NO.:
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): Map Projections and Grid Systems for Meteorological Applications
5. TYPE OF REPORT & PERIOD COVERED:
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s):

James E. Hoke
John L. Hayes
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8. CONTRACT OR GRANT NUMBER(s):
9. PERFORMING ORGANIZATION NAME AND ADDRESS: HQ Air Force Global Weather Central (MAC), Offutt AFB, Nebraska 68113
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
11. CONTROLLING OFFICE NAME AND ADDRESS: HQ Air Force Global Weather Central (MAC), Offutt AFB, Nebraska 68113
12. REPORT DATE: March 1981
13. NUMBER OF PAGES: 86 + xii
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): (same as block 9)
15. SECURITY CLASS. (of this report): UNCLASSIFIED
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report): N/A
18. SUPPLEMENTARY NOTES:
19. KEY WORDS (Continue on reverse side if necessary and identify by block number):

Maps
Grids
Projections
Meteorological data base
Numerical Weather Analysis
Numerical Weather Prediction

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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PREFACE

This Technical Note describes the maps and grids currently used at the Air Force Global Weather Central (AFGWC) to provide conventional meteorological support. It does not discuss those used for space environmental support, however. The emphasis is on the mathematical equations needed for proper earth location of meteorological data on both maps and grids. This Technical Note is intended to serve as a reference for programmers. In addition, it provides information for users of AFGWC products and the meteorological community at large.

To keep this publication as current and useful as possible, we ask your help. Please direct your comments on, for example, errors or possible additional topics to AFGWC/TS, Offutt Air Force Base, Nebraska 68113.

This publication could not have been completed without the help of many people:

Mr. H. A. Bedient, National Meteorological Center, Automation Division, for sharing his firsthand knowledge of the development of grid systems in the early days of operational numerical weather prediction.

Major James Hatch, AFGWC/DOY, for providing his insight on important subjects to be included and information on the Satellite Global Data Base and Three-dimensional Nephanalysis portions.

Lieutenant Colonel William Irvine, Jr., AFGWC/TSI, and Major Terry Tarbell, AFGWC/TSIN, for their tremendous support, guidance, and encouragement throughout the project.

Captain Don Janssen, AFGWC/ADSS, for his help with the Satellite Global Data Base sections.

Mr. Andrew Johnson, formerly AFGWC/WPDL, for his initial work on the grids portion of this Technical Note.

Capt Fred Lewis, AFGWC/TSIN, for his work in determining the orientation of coordinate axes for the grid systems.

Major Michael Lewis, formerly AFGWC/DOY, for providing important ideas on the scope and nature of this publication.

Mrs. Irene Stubbs and Mr. Henry Hacia, Environmental Science Information Center, Library and Information Services Division, Camp Springs Center, for their assistance in obtaining technical literature upon which part of this Technical Note is based.

The following members of the Target Acquisition Section, AFGWC/TSIT, for their assistance with the grid systems used in cloud analysis and forecasting:

Major Arnold Friend,
Captain Kenneth Mitchell,
Captain Thomas Walters.

The many people of the 544th Strategic Intelligence Wing, Target Materials Squadron, Photographic Services Branch, for their outstanding, timely, and professional photographic support, which was a key element in the preparation of this Technical Note.

The following reviewers, for their very valuable comments and suggestions:

Mr. Arthur Gulliver, AFGWC/DO,
Lieutenant Colonel William Irvine, Jr., AFGWC/TSI,
Lieutenant Colonel Ronald Lininger, AFGWC/TSA,
Captain Kenneth Mitchell, AFGWC/TSIT,
Major Terry Tarbell, AFGWC/TSIN.

For their clerical and administrative support, Staff Sergeant Kathleen Tittle, AFGWC/TSA, and the following members of the AFGWC Word Processing Center:

Mary Ann Kosmicki,
Mary DeSessa,
Meiissa Hockman.

Doctor James E. Hoke
Captain John L. Hayes
Second Lieutenant Larry G. Renninger

20 March 1981

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LIST OF SYMBOLS

The symbology for this Technical Note is summarized in this section. Definitions and acronyms are given in the Glossary.

a Radius of the earth. The radius of a sphere having the same volume as the earth is 6371.2213 km.

B_n – 3DNEPH box number.

B_s – SGDB box number.

d_e – Distance between grid points on the earth's surface.

d_e' – Distance between grid points on the earth's surface in the north-south direction on a Mercator projection.

d_i – Distance between grid points on the image plane.

d_m – Distance between grid points on the map.

d_o – The distance of 381 km. Among other things, this distance equals the whole-mesh grid length at 600N (or °S) for polar stereographic projections, as well as the distance between grid points on the image plane for polar stereographic projections true at 600N (or °S).

G – Grid designator for Mercator grids.

H – Designator of the hemisphere on which a polar stereographic projection is centered.

I – Indicator of position relative to grid points in the $\pm x$ direction.

I' – I index for a second grid.

IM – Total number of points in the east-west direction for a Mercator grid.

IN – Number of nonduplicated points in the east-west direction for a Mercator grid.

In – I index for the 3DNEPH Box IJ convention.

I_{np} – I index of the North Pole.

IP – I index of the pole.

I_p' – I index of the pole for a second grid.

I_s I index for the SGDB Box IJ convention as used in this Technical Note.

I_s' - I index for the SGDB Box IJ convention as used in SYNAPS.

I_{sp} - I index of the South Pole.

I_W - I index for a whole-mesh grid.

I_w' - I index for a whole-mesh grid as used in SYNAPS.

I_2 - I index for a half-mesh grid.

I_4 - I index for a quarter-mesh grid.

I_8 - I index for an eighth-mesh grid.

I_{64} - I index for a sixty-fourth-mesh grid.

I_{64}' - I index for a sixty-fourth-mesh grid as used in SYNAPS.

J - Indicator of position relative to grid points in the $\pm y$ direction.

J' - J index for a second grid.

JE - J index of the Equator for a Mercator grid.

JM - Number of points in the north-south direction for a Mercator grid.

J_n - J index for the 3DNEPH Box IJ convention.

J_{np} - J index of the North Pole.

J_p - J index of the pole.

J_p' - J index of the pole for a second grid.

JS - J index for the SGDB Box IJ convention as used in this Technical Note.

J_s' - J index for the SGDB Box IJ convention as used in SYNAPS.

J_{sp} - J index of the South Pole.

J_w - J index for a whole-mesh grid.

J_w' - J index for a whole-mesh grid as used in SYNAPS.

J_2 - J index for a half-mesh grid.

J_4 - J index for a quarter-mesh grid.

J_8 - J index for an eighth-mesh grid.

J_{64} - J index for a sixty-fourth-mesh grid.

J_{64}' - J index for a sixty-fourth-mesh grid as used in SYNAPS.

K - Any integer.

M - Mesh factor.

M' - Mesh factor for a second grid.

m - Map factor.

n - Constant of the cone.

RM - Radial distance on the image plane between the pole and a given latitude in multiples of grid length d_i.

r - Radial coordinate of the image-plane polar coordinate system (r,θ).

S - Scaling parameter defined for polar stereographic projections so that whole-mesh grid points are exactly 381 km apart at 60°N (or $^{\circ}$S) on the earth's surface, regardless of the standard latitude.

u - Wind component in the $\pm x$ direction.

v - Wind component in the $\pm y$ direction.

X - Grid-point Cartesian coordinate in the x direction; expressed in multiples of grid length di (which is a function of mesh size) from the y axis.

X_w - X coordinate for a whole-mesh grid.

x - A coordinate of the image-plane Cartesian coordinate system (x,y). The distance x from the y axis is with respect to the image plane, not the surface of the earth.

Y - Grid-point Cartesian coordinate in the y direction; expressed in multiples of grid length di (which is a function of mesh size) from the x axis.

Y_w - Y coordinate for a whole-mesh grid.

Y - A coordinate of the image-plane Cartesian coordinate system (x,y). The distance y from the x axis is with respect to the image plane, not the surface of the earth.

$\Delta\lambda$ - Longitudinal (east-west) spacing between grid points.

$\Delta\phi$ - Latitudinal (north-south) spacing between grid points.

θ - Azimuthal coordinate of the image-plane polar coordinate system (r,θ).

- Longitude.

λ_o	- Reference longitude.
μ	- Map scale.
π	- The constant 3.14159...
σ	- Image scale.
ϕ	- Latitude.
ϕ_o	- The standard latitude for a polar stereographic projection.
ϕ_1	- A standard latitude for a Mercator or Lambert conformal projection.
ϕ_2	- A standard latitude for a Mercator or Lambert conformal projection.

SECTION 1. INTRODUCTION

The AFGWC system of maps and grids has evolved over the past 20 years. The system in its present form is large and complex. Tarbell and Hoke (1979) described factors that have led to the present form of the AFGWC analysis/forecast system. These same factors have led to the development of the system of maps and grids used to support the AFGWC analysis/forecast system. These factors include:

a. AFGWC's mission to provide worldwide meteorological support.

b. The continual development of meteorological analysis and forecast models and techniques at AFGWC and other locations in the meteorological community.

c. The specific hardware at AFGWC.

d. The continual technological development of systems for taking meteorological observations, especially meteorological satellites.

e. A greater availability of data in the Northern Hemisphere than in the Southern Hemisphere.

f. A larger number of operational requirements in the Northern Hemisphere.

g. The need for grids compatible with those of other U.S. numerical weather centers.

In view of the above reasons, no master plan addressing the entire system of maps and grids was possible when the system was initiated. Even today changing operational requirements are reflected by the changing automated analysis/forecast system. The system of maps and grids must change with it.

There are two general classes of environmental support provided at AFGWC: meteorological and space environmental. Meteorological support includes observation, analysis, and forecasting of the tropospheric and stratospheric environment. Space environmental support includes observation, analysis, and forecasting of the space and near-space environment. Although some of the maps and grids are not common to both, only those used to provide meteorological support will be discussed in this Technical Note.

The mathematical details of the derivations of the various projections and maps are not presented here. Also, we do not discuss the formulation of equations, such as the equations of motion, on the various projections. Excellent discussions of these topics may be found in publications by Deetz and Adams (1945), Thomas (1952), Richardus and Adler (1972), Gerrity (1973), and Williamson (1979), for example.

We discuss the projections and maps most commonly used at AF'GWC in Section 2, with the latitude and longitude conventions used in this publication defined in Section 2.1. Section 3 details the AFGWC grid systems. The domains of the Northern and Southern Hemispheric regions for identifying and storing observations are depicted in Section 4. Section 5 is a glossary of the most important terms presented in this Technical Note. A list of references is presented in Section 6.

SECTION 2. PROJECTIONS AND MAPS

The map has become a basic tool of the meteorologist. Saucier (1955) noted that meteorological maps (charts) used to represent and interpret the state of the atmosphere "must best portray the space variations of the atmospheric variables with consideration for convenience in plotting and analysis, for accuracy in representation, and for interpretation". In this section we present the mathematical bases for the polar stereographic, Mercator, and Lambert conformal projections and maps, which are three popular systems for satisfying Saucier's requirements.

2.1 CONVENTIONS FOR LATITUDE AND LONGITUDE

Before discussion of map projections, it is necessary to specify the conventions for locating points on the earth's surface by latitude ϕ and longitude λ. For latitude, Northern Hemispheric locations are designated in this Technical Note by $^\circ$N increasing northward or by positive values (without the N) increasing northward. Southern Hemispheric latitudes are designated by $^\circ$S increasing southward or by negative values (without the S) increasing northward. For example, the South Pole is at 90°S, or -90°.

For longitude, Eastern Hemispheric locations are indicated by $^\circ$E increasing eastward or by positive values between 0° and 180° (without the E) increasing eastward. Western Hemispheric locations are indicated by $^\circ$W increasing westward, negative values between -180° and 0° (without the W) increasing eastward, or positive values between 180° and 360° (without the W) increasing eastward. As example, 90°E is the same as 90°, and 90°W is the same as -90° and 270°.

The equations presented in subsequent sections are valid for those conventions not using the alphabetical designators (N, S, E, W). It is important to note that in specific applications at AFGWC, latitude-longitude conventions different from those of this Technical Note might be used. As an example, in the global Hough analysis (HUFANL) longitude increases toward the west.

2.2 MAP CONSTRUCTION AND SCALE FACTORS

As used at AFGWC, the term <u>map</u> may be defined as a two-dimensional horizontal representation of the surface of the earth with size convenient for display, analysis, and interpretation of meteorological data. The fundamental problem in map construction is the transfer of the earth's geography from its actual three-dimensional form to a flat surface in such a way as to present the earth's surface most advantageously. Conceptually, two transformations are necessary: first, the curved surface of the earth must be transformed to a two-dimensional surface; second, this two-dimensional surface must be reduced to a convenient size.

The first transformation has several steps. First, the irregularly curved surface of the earth is transformed into a regularly shaped surface, usually the sphere or ellipsoid. In subsequent discussions in this Technical Note, we will assume that this first step of the first transformation has been performed so that the earth may be considered spherical. In the second step the regularly shaped three-dimensional surface is transformed into a two-dimensional one. As will be discussed in the next section this step can be done in three different ways. In one way the earth's surface is projected using straight lines, called rays, onto a geometric figure, such as the cone in Fig. 2.1, a cylinder, or a plane. Then the surface might be stretched to produce some desirable quality, such as conservation of shape or area, on the resultant surface (the image surface). Finally, if necessary, this surface is cut and unfolded, a process called developing, to produce a planar surface--the image plane (see Fig. 2.2). The representation of the surface of the earth on the image surface or image plane is called the projection. The transformation from curved earth surface to image surface or image plane is described mathematically, in part, by the image scale σ, which is the ratio at a point of (differential) distance on the image surface or image plane to (differential) distance on the surface of the earth. The mathematical expression for image scale varies according to projection and is described in more detail in Sections 2.4.2, 2.5.2, and 2.6.2.

The second transformation consists of uniformly reducing the image plane to a size suitable for the purpose intended to produce a map, or map surface. This transformation is described mathematically by the map scale μ, which is the ratio of distance on the map to distance on the image surface or image plane. The map scale specifies the image-plane reduction necessary to form the particular map; for example, $\mu = 1{:}7{,}500{,}000$ refers to a map generated by uniformly reducing image-plane distances by a factor of 7,500,000. Maps commonly used at AFGWC vary in map scale from 1:60,000,000 to 1:3,750,000.

Both transformations can be described by one factor called the map factor m, where

$$m = \sigma\mu \quad . \tag{2.1}$$

Thus, m is the ratio at a point of (differential) distance on a map to (differential) distance on the earth.

2.3 CLASSIFICATION OF PROJECTIONS AND MAPS

As previously noted, a particular map is selected so that its characteristics best suit the purpose of the user. Because the number of unique projections and maps is infinite, a general classification scheme is needed. Richardus and Adler (1972) presented a scheme suggested by Goussinsky (1951) in which five general classes, which were not mutually exclusive, were defined. Each class was partitioned into mutually exclusive subclasses, called varieties. This scheme is summarized here because it offers a simple, yet comprehensive, method of classifying projections and maps. The five general classes of the Goussinsky scheme are nature, coincidence, position, properties, and generation.

Nature describes the geometric figure associated with the image surface. The plane, cone, and cylinder represent the only universally recognized varieties of the nature class; all three are associated with maps for meteorological use.

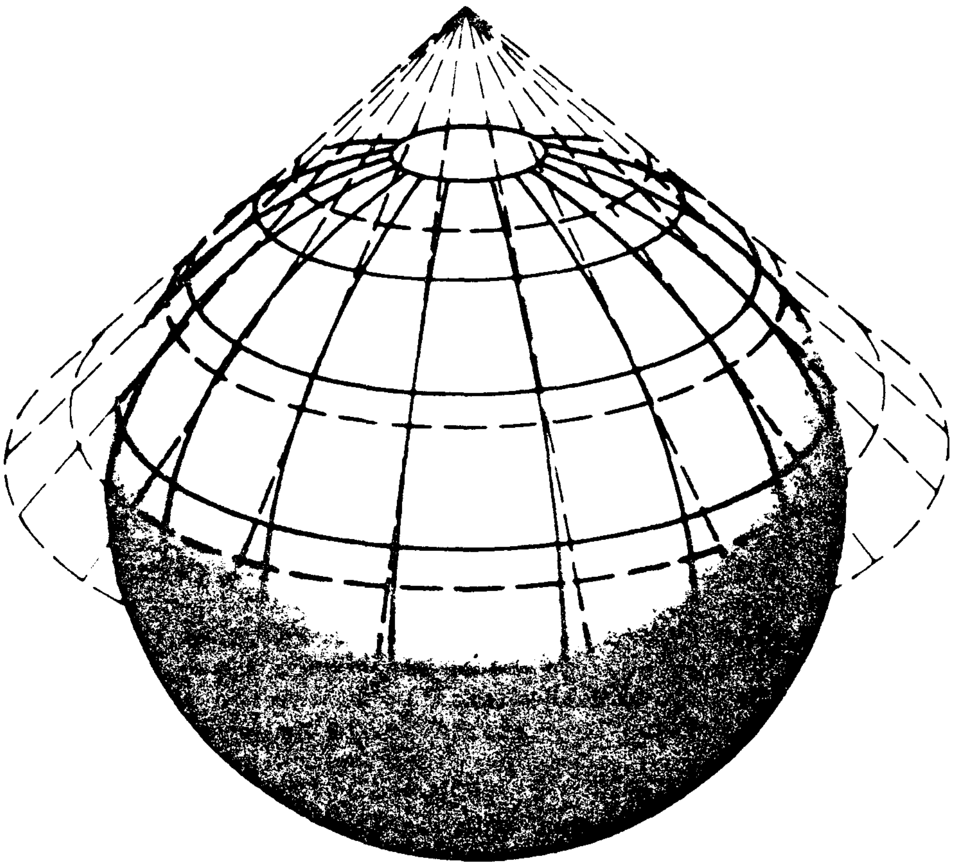


Figure 2.1. Projection of the surface of the earth onto a cone (© Strahler, 1969; John Wiley and Sons, Inc., Publishers).

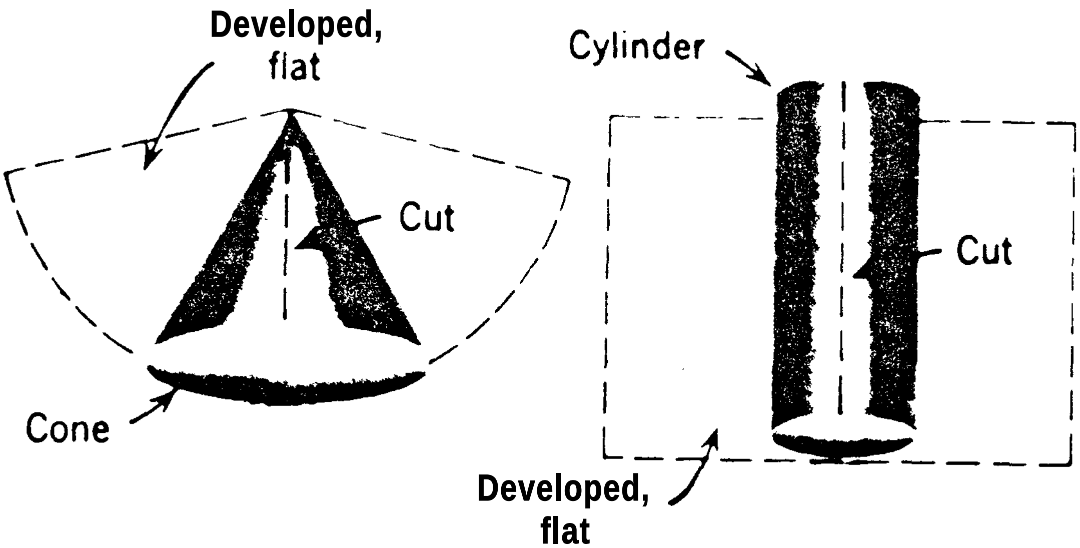


Figure 2.2. Transformation of image surfaces into image planes by cutting and unfolding (after © Strahler, 1969; John Wiley and Sons, Inc., Publishers).

Coincidence refers to the type of contact between the geometric figure and the earth. Three varieties have been defined (Fig. 2.3). The tangent variety includes all projections in which the geometric figure is tangent to the earth. In the secant variety, the geometric figure intersects the interior of the earth. In the polysuperficial variety, a succession of different geometric figures is used to construct one projection. Although the polysuperficial variety is most accurate, the resulting maps are cumbersome and the transformation equations are quite complex. The tangent and secant varieties, on the other hand, often produce easy-to-use maps with an acceptable amount of distortion, and, consequently, serve as a basis for most meteorological maps.

Position refers to the alignment of the geometric figure with respect to the axis of the earth (Fig. 2.4). In the normal position, the axis of symmetry of the geometric figure coincides with the rotational axis of the earth. In the transverse position, the axis of symmetry is perpendicular to the earth's axis. Those projections in which the axis of symmetry is neither perpendicular to nor coincident with the earth's axis belong to the oblique variety. The normal variety of geometric figure is most widely used because a primary interest of the meteorologist is atmospheric phenomena that, in general, move about the earth's axis.

There are three mutually exclusive varieties of the property class. Equidistance is defined as correct representation of distance between two points. This property is limited to certain specified points and cannot be generalized over an entire image surface. In the equivalent variety, areas of features on the earth are preserved on the image surface; correct representation of shapes, however, is sacrificed. The conformal (or orthomorphic) variety includes image surfaces in which the angles between intersecting curves and, therefore, the shapes of small features on the earth's surface are preserved. Also, a differentially small distance on the projection will correspond to a distance on the earth's surface independent of direction from the point. Conformal maps are used extensively in meteorology. Their accurate representation of geographical shapes facilitates the interpretation of meteorological data.

The generation class describes the method used to construct the image surface. For teometricg (or perspective) variety, the surface of the earth is simply projected using rays onto a geometric figure. The conventional variety includes projections generated purely mathematically without regard to projection using rays. The semi-geometric variety is a combination of the geometric and conventional varieties.

The Goussinsky classification scheme is summarized in Table 2.1. As is readily apparent, there is a large number of unique possibilities. Projections used as a basis for meteorological maps represent only a small subset of this number. At AFGWC, extensive use is made of polar stereographic and Mercator maps, produced from polar stereographic and Mercator projections, respectively. In addition, some specialized support is provided using Lambert conforrnal maps. The Goussinsky classification as it relates to AFGWC projections and maps is shown in Table 2.2. The three projections and maps most commonly used in meteorological applications will be described in detail in the remainder of this chapter.

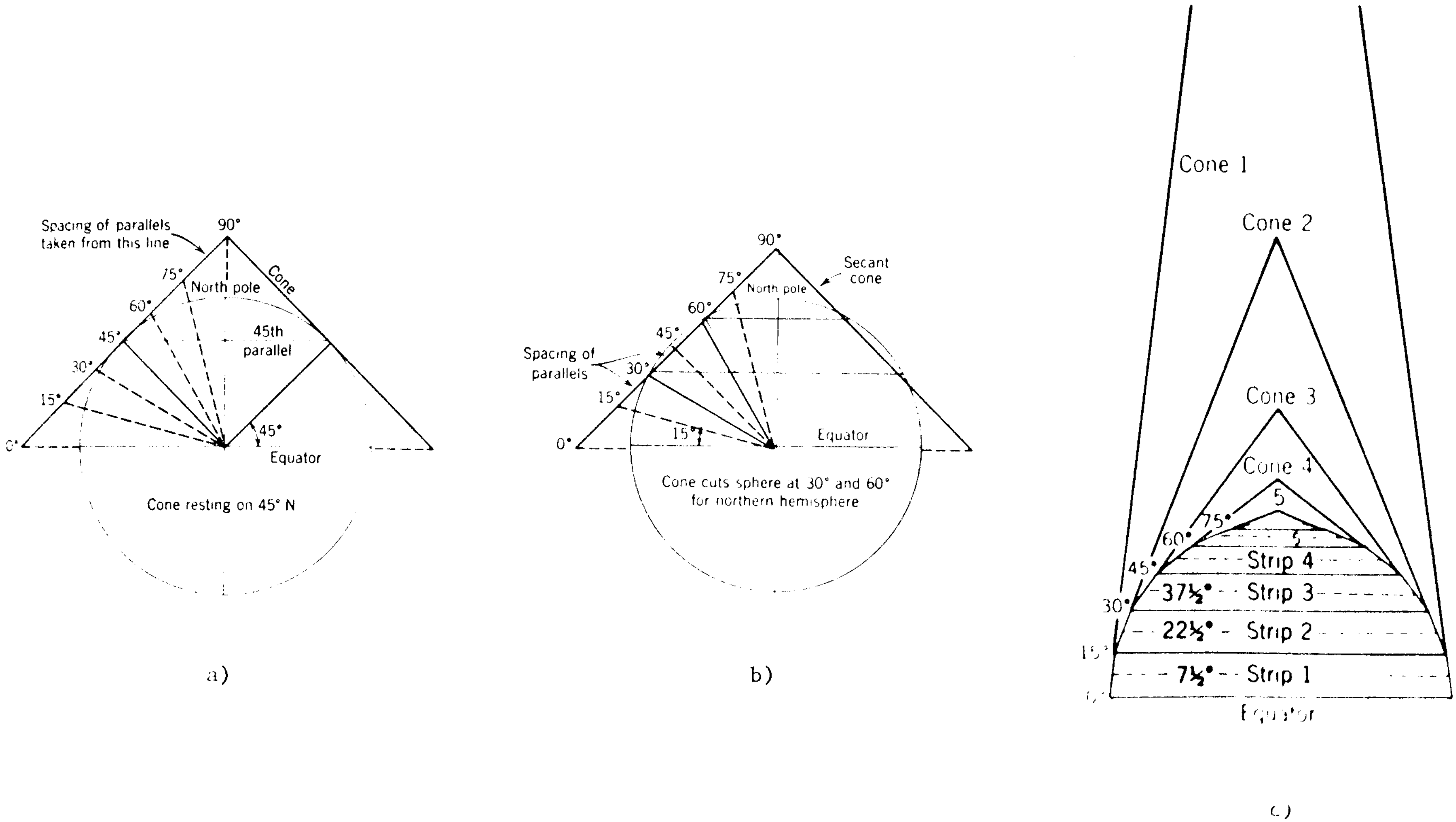
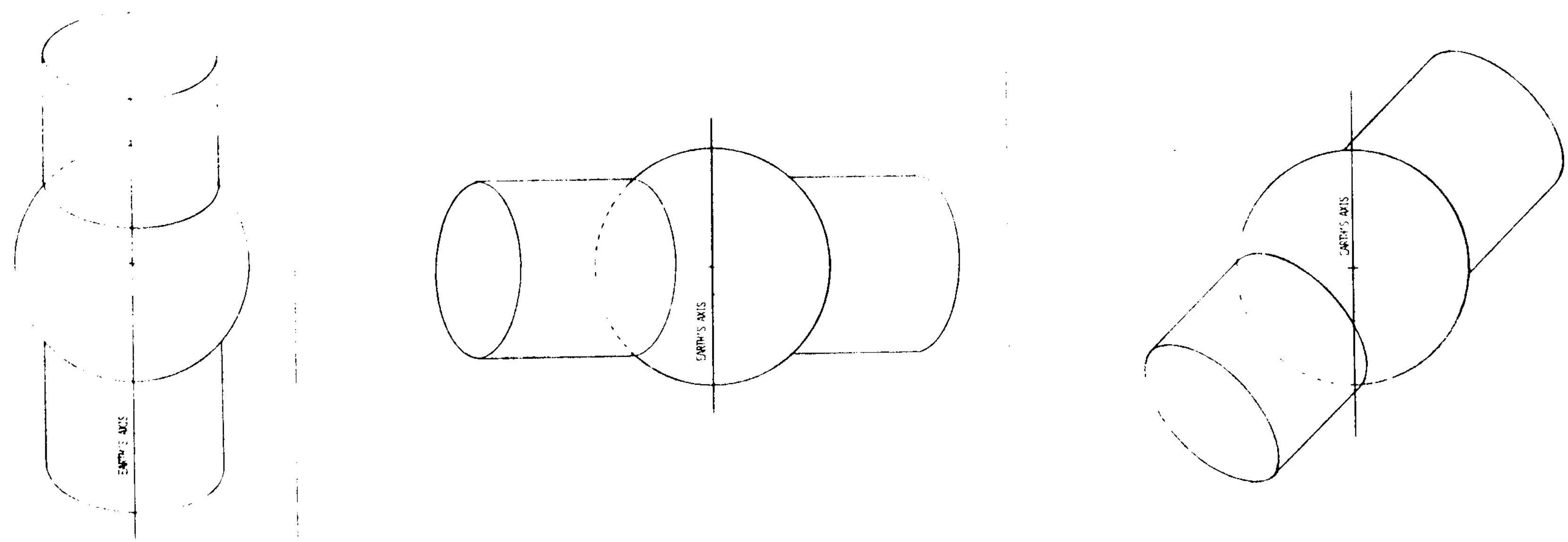


Figure 2.3. Examples (for a cone) of the three varieties of coincidence: a) tangent, b) secant, and c) polysuperficial (©Strahler, 1969; John Wiley and Sons, Inc., Publishers).



a) b) c)

Figure 2.4. Examples (for a cylinder) of the three varieties of position: a) normal, b) transverse, and c) oblique.

Table 2.1. Summary of the Goussinsky Classification Scheme (Goussinsky, 1951).

CLASS	VARIETIES
Nature	Planar, Conical, Cylindrical
Coincidence	Tangent, Secant, Polysuperficial
Position	Normal, Transverse, Oblique
Property	Equidistant, Equivalent, Conformal
Generation	Geometric, Conventional, Semi-geometric

Table 2.2. Goussinsky Classification Scheme for AFGWC Projections and Maps.

PROJECTION/MAP	NATURE	COINCI-DENCE	POSITION	PROPERTY	GENERATION
Northern Hemispheric Polar Stereographic	Planar	Secant	Normal	Conformal	Geometric
Southern Hemispheric Polar Stereographic	Planar	Secant	Normal	Conformal	Geometric
Mercator	Cylin-dridcal	Secant	Normal	Conformal	Semi-geometric
Lambert Conformal	Conical	Secant	Normal	Conformal	Conventional

2.4 POLAR STEREOGRAPHIC PROJECTIONS AND MAPS

The secant polar stereographic projection is used extensively at AFGWC. This projection is generated geometrically (that is, using rays) by positioning a secant plane normal to the earth's axis at a standard latitude. (Fig. 2.5a illustrates the geometry for the Northern Hemispheric polar stereographic projection.) The resulting projection has the conformal property. In the special case that the standard latitude is a pole (ϕ_o = 90°N and 90°S for Northern Hemispheric and Southern Hemispheric polar stereographic projections, respectively), a tangent polar stereographic projection is formed (Fig 2.5b). The tangent projection is used at some meteorological facilities although AFGWC is not one of them.

In the following discussion, the equations for the secant polar stereographic projection and map will be presented. The equations for the tangent case are obtained using ϕ_o = 90°N or °S.

2.4.1 GENERATION OF THE SECANT POLAR STEREOGRAPHIC MAP

The secant polar stereographic map is formed in the following manner. First, a plane, which is the geometric figure for this projection, is passed through the earth (perpendicular to the earth's axis) at a <u>standard latitude</u>, or <u>true latitude</u>, ϕ_o, as shown in Fig. 2.5a. At AFGWC, ϕ_o= 600N is used for the Northern Hemispheric polar stereographic projection and ϕ_o = 60°S for the Southern Hemispheric polar stereographic projection. Next, for each latitude ϕ a straight line, or ray, is drawn through the pole (point P) of the opposite hemisphere and the surface of the earth (point E). This ray (ray PIE in Fig. 2.5a) projects the surface of the earth onto the plane, the image plane and image surface in this case, at point I. After the desired points on the earth's surface are projected the image plane is reduced to a map of manageable size by means of the map scale μ (see Section 2.2).

The image plane (image surface) and map (Fig. 2.6) are conformal and have the following characteristics:

a. Lines of constant latitude are concentric circles centered at the pole.

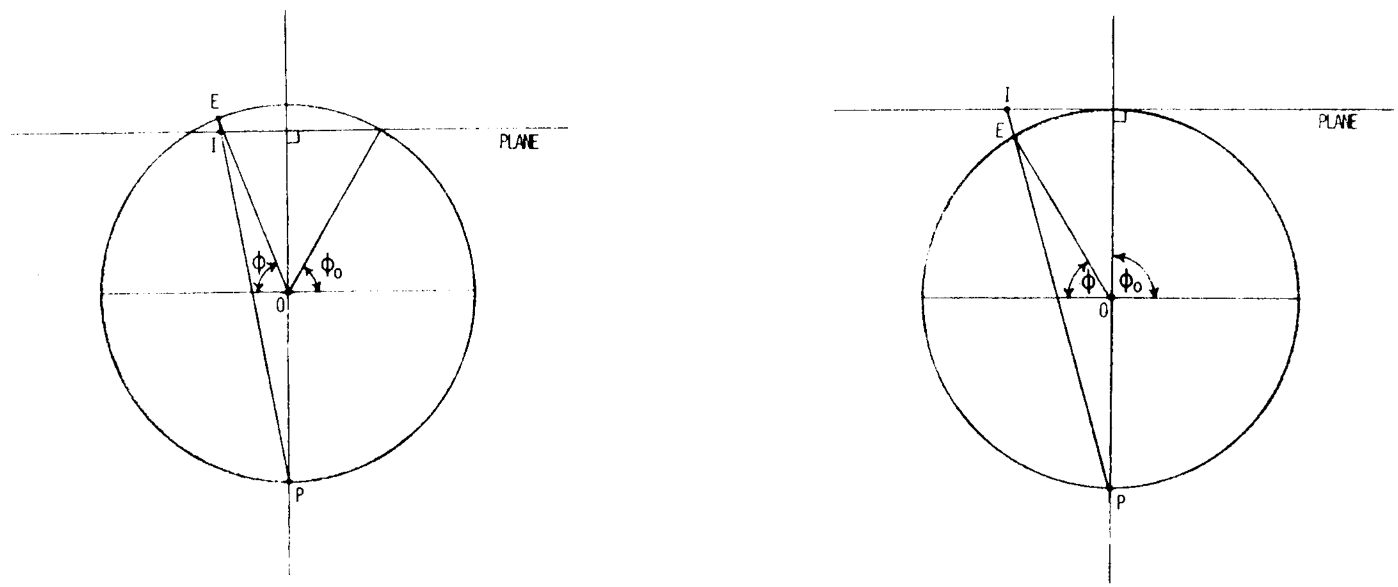
b. Lines of constant longitude (meridians) are depicted as straight lines radiating from the pole. These radials are spaced at the same angular increment as meridians on the earth.

2.4.2 POLAR STEREOGRAPHIC IMAGE SCALE

As noted previously, image scale accounts for the transformation from the earth's surface to the image surface or image plane and is the ratio of distance on the image surface or image plane to distance on the earth's surface. For a polar stereographic projection true at latitude ϕ_o, the image scale a is given by

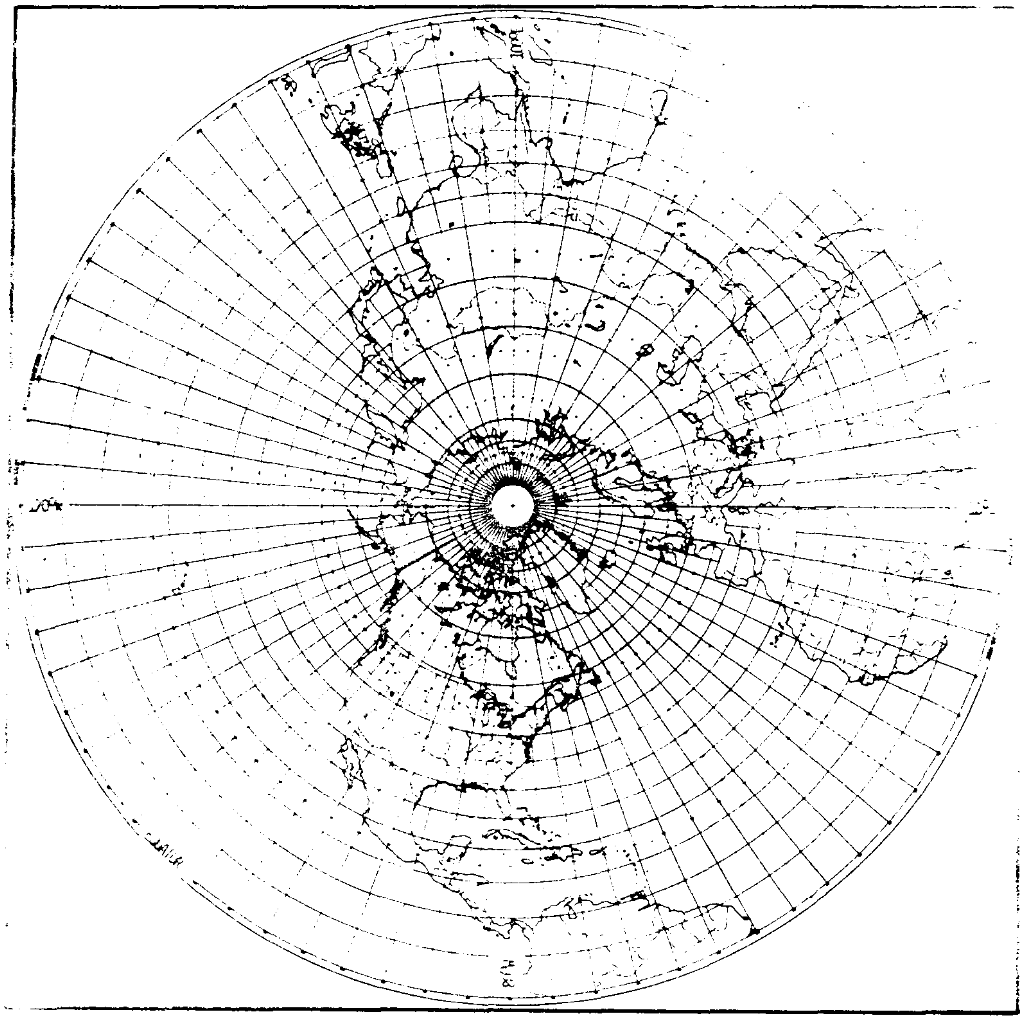
$$\sigma(\phi) = \frac{1 + H \sin\phi_o}{1 + H \sin\phi} , \qquad (2.2)$$

where ϕ is latitude. Eq. (2.2) is valid for both Northern and Southern Hemispheric polar stereographic projections, with



a) b)

Figure 2.5. Side view of the geometry for constructing Northern Hemispheric polar stereographic projections: a) secant variety (standard latitude $\phi_o = 60^oN$) and b) tangent variety ($\phi_o = 90^oN$). The South Pole is designated by P and the earth's center by O. The point E at latitude : on the earth's surface is projected onto point I on the geometric figure, a plane.



.· _ . . Norcnern hemispheric poiar stereographic sap.

$$H = \begin{cases} +1, & \text{Northern Hemispheric projection,} \\ -1, & \text{Southern Hemispheric projection.} \end{cases} \quad (2.3)$$

Note that Southern Hemispheric locations ($\phi < 0°$) may exist on a Northern Hemispheric projection ($H = +1$), and vice versa. The latitudinal variation of image scale is shown in Fig. 2.7. The solid curve is the secant case for ϕ_o = 60°N or °S and the dashed curve is the tangent case (ϕ_o = 90°N or °S). Earth distance is preserved on the image plane (image surface) only at the true latitude ϕ_o, where $\sigma = 1$. Poleward of latitude ϕ_o the distance between two points is larger on the earth than on the image plane (image surface), whereas equatorward of ϕ_o the distance is smaller on the earth.

2.4.3 IMAGE-PLANE COORDINATE SYSTEMS

An <u>image-plane Cartesian coordinate system</u> (x,y) can be defined for the polar stereographic image planes. The orientation of the coordinate axes for the Northern and Southern Hemispheres is shown in Figs. 3.6 and 3.7, respectively. In both hemispheres the origin is the pole, the positive x axis coincides with the 10°E meridian, and the positive y axis coincides with the 100°E meridian. These orientations result in a right-handed system for the Northern Hemispheric projection and a left-handed system for the Southern Hemispheric projection. The image-plane Cartesian coordinates of any point on the earth's surface are given by

$$x = \sigma\, a \cos\phi \, \cos(\lambda - \lambda_o) \quad , \qquad (2.4)$$

$$y = \sigma\, a \cos\phi \, \sin(\lambda - \lambda_o) \quad , \qquad (2.5)$$

where σ is the image scale, ϕ is the latitude, A is the longitude, λ_o is the reference longitude of the positive x axis (at AFGWC, λ_o = 10°E), an8 a is the earth's radius. In this Technical Note we use the radius of a sphere having the same volume as the earth for <u>a</u>,

$$a = 6371.2213 \text{ km} . \qquad (2.6)$$

Certain numerical models at AFGWC may use slightly different values for a.

A corresponding <u>image-plane polar coordinate system</u> (r,θ) has also been defined. As shown in Figs. 3.6 and 3.7, radial distance r increases with distance from the pole. Also, azimuth θ increases from the reference longitude, λ_o = 10°E, in the counter-clockwise direction on the Northern Hemispheric projection and the clockwise direction on the Southern Hemispheric projection. The polar coordinates on the image planes are given by

$$r = \sigma\, a \cos\phi \quad , \qquad (2.7)$$

$$\theta = \lambda - \lambda_o \qquad (2.8)$$

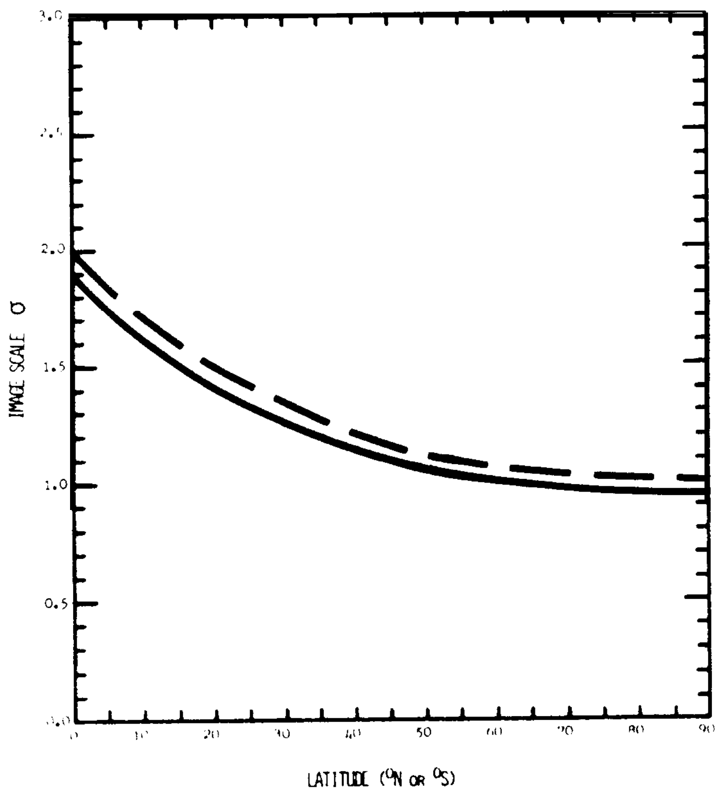


Figure 2.7. The latitudinal variation of image scale σ for polar stereographic projections true at 60°N or °S (solid line) and 90°N or °S (dashed line). Not plotted is the image scale for these projections extending into the opposite hemisphere.

2.5 MERCATOR PROJECTIONS AND MAPS

A secant Mercator projection is used at AFGWC for certain tropical applications. Although in our discussion we employ the cylinder as the geometric figure used in the construction of the Mercator projection, this projection was originally derived without consideration of geometric figure by Gerhardus Mercator for its navigational benefits (Deetz and Adams, 1945). This conformal projection can be generated semi-geometrically by projecting the earth's surface onto a normally positioned cylinder that intersects the earth at standard latitudes ϕ_1 and ϕ_2 (Fig. 2.8a) and then shrinking the result in the north-south direction. For the case where $\phi_1 = \phi_2 = 0^o$ (Fig. 2.8b) the tangent Mercator projection is obtained.

In the following discussion, the equations of the secant Mercator projection and map will be presented. Equations for the tangent case are obtained using $\phi_1 = \phi_2 = 0^o$.

2.5.1 GENERATION OF THE SECANT MERCATOR MAP

The secant Mercator map can be derived in the following manner. First, a cylinder, which is the geometric figure for this projection, is aligned so that its axis coincides with the earth's axis and intersects the earth's surface at latitudes ϕ_1 and ϕ_2. For AFGWC projections, $\phi_1 = 22.5^oN$ and $\phi_2 = 22.5^oS$. Secondly, for each latitude ϕ a ray is drawn through the center of the earth (point O) and the earth's surface (point E). This ray (ray OEI in Fig. 2.8a) projects the surface of the earth onto the geometric figure, the cylinder, at point I. In Fig. 2.8a, ray OI'E' projects the Equator onto the cylinder. After the desired points on the earth's surface are projected, the resultant is shrunk in the north-south direction to obtain an image surface that is conformal. Next, the image surface is developed into the image plane by cutting the image surface along a reference meridian and unrolling. Finally, the image plane is reduced to a map of manageable size by means of the map scale μ.

On the image plane and map (Fig. 2.9), latitude circles are depicted as parallel straight lines spaced as a function of latitude. Meridians are depicted as equally spaced, parallel straight lines and are oriented perpendicular *to* the latitude lines. Spacing between meridians on the image plane is equal to spacing between meridians on the earth at the standard latitudes. Loxodromes (lines of constant bearing) are straight lines on the image plane and map.

2.5.2 MERCATOR IMAGE SCALE

For Mercator projections true at latitudes ϕ_1 and ϕ_2, image scale is a function of latitude ϕ and is given by

$$\sigma(\phi) = \cos\phi_1 \sec\phi = \cos\phi_2 \sec\phi \quad . \qquad (2.9)$$

The latitudinal variation of image scale is shown in Fig. 2.10 where the solid curve represents the secant projection (for $\phi_1 = 22.5^oN$, $\phi_2 = 22.5^oS$) an3 the dashed curve represents a tangent projection ($\phi_1 = \phi_2 = 0^o$). In

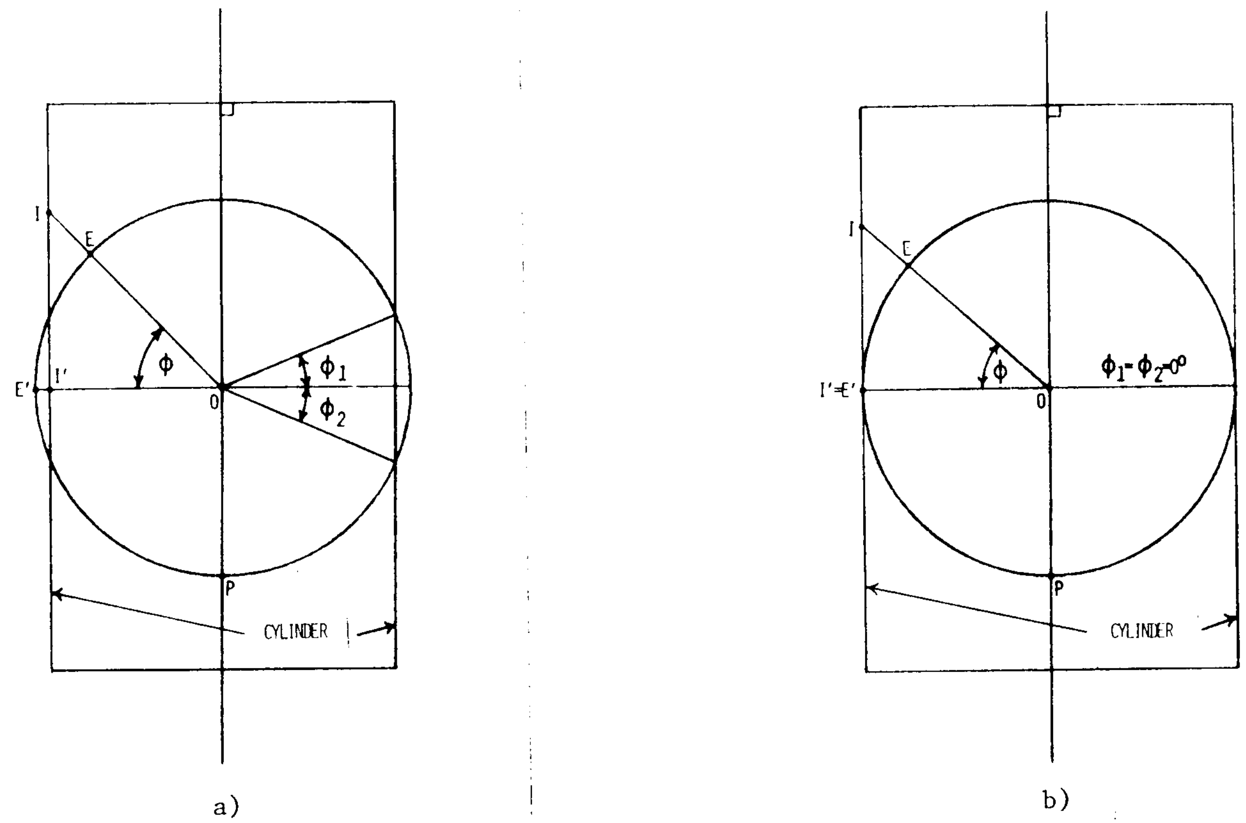


Figure 2.8. Side view of the geometry for projecting the earth onto a cylinder: a) secant variety (standard latitudes (ϕ_1 = 22.5°N, ϕ_2 = 22.5°S), and b) tangent variety ($\phi_1 = \phi_2 = 0°$). The South Pole is designated by P and the earth's center by O. The point E at latitude ϕ on the earth's surface is projected onto point I on the geometric figure, the cylinder. The point E' at the Equator is projected onto point I'.

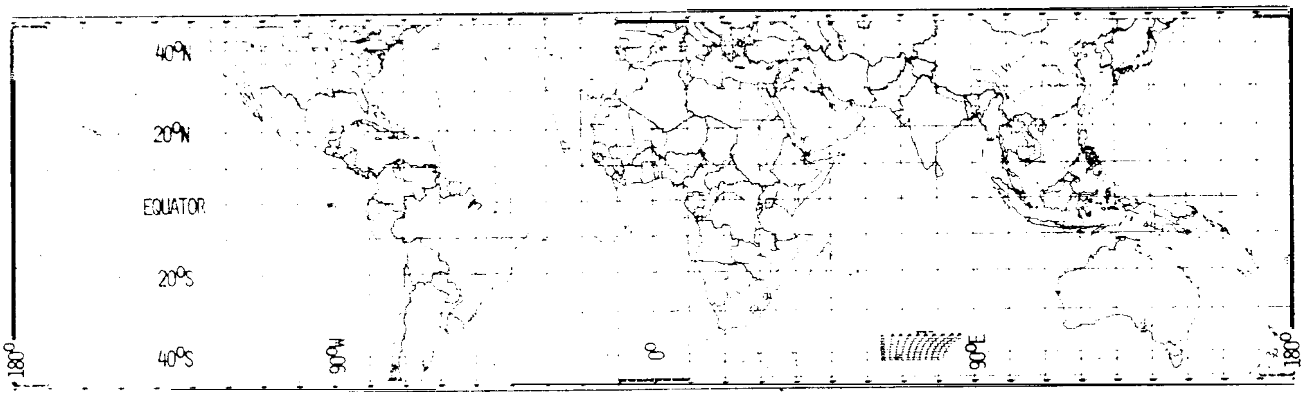


Figure 2.9. Mercator map.

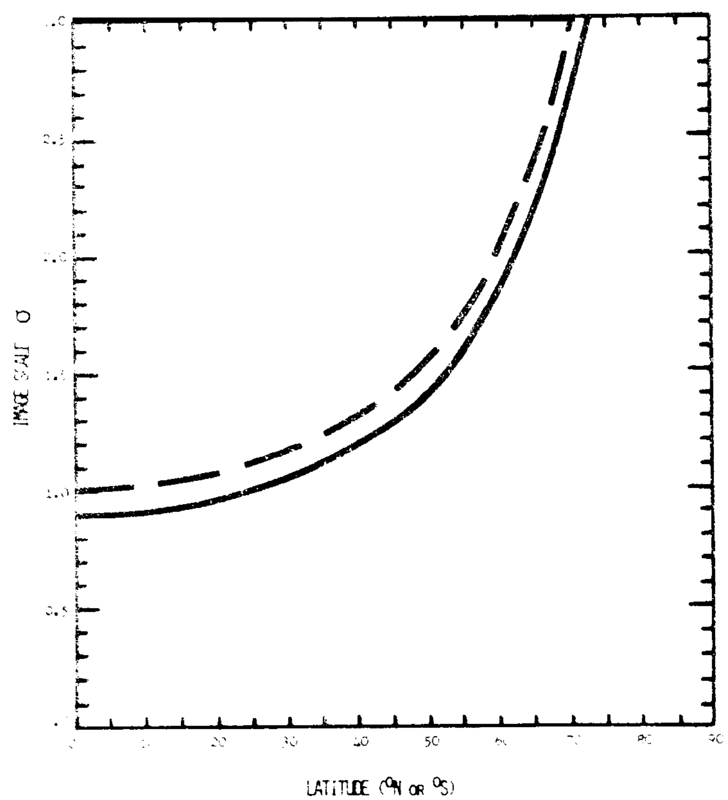


Figure 2.10. The latitudinal variation of image scale σ for Mercator projections true at $22.5^{o}N/22.5^{o}S$ (solid line) and 0^{o} (dashed line). The image scale as a function of latitude is symmetric about the Equator.

this secant case, earth distance is preserved on the image plane (image surface) at 22.5°N and 22.5°S (where $\sigma = 1$). Equatorward of these latitudes, σ is less than unity so that the distance between two points is greater on the earth than on the image plane (image surface), whereas poleward of ϕ_1 and ϕ_2 the distance is smaller on the earth.

2.5.3 IMAGE-PLANE COORDINATE SYSTEM

A right-handed image-plane Cartesian coordinate system (x,y) is defined for the Mercator projection. Orientation of the coordinate axes is shown in Fig. 3.24. The (x,y) coordinates of any point on the image plane are given in terms of the point's latitude and longitude by the following equations:

$$x = \begin{cases} a \left(\dfrac{\pi}{180^\circ}\right) (\lambda-\lambda_o) \cos\phi_1 , & \lambda \text{ and } \lambda_o \text{ in degrees,} \\ a\,(\lambda-\lambda_o) \cos\phi_1 , & \lambda \text{ and } \lambda_o \text{ in radians,} \end{cases} \tag{2.10}$$

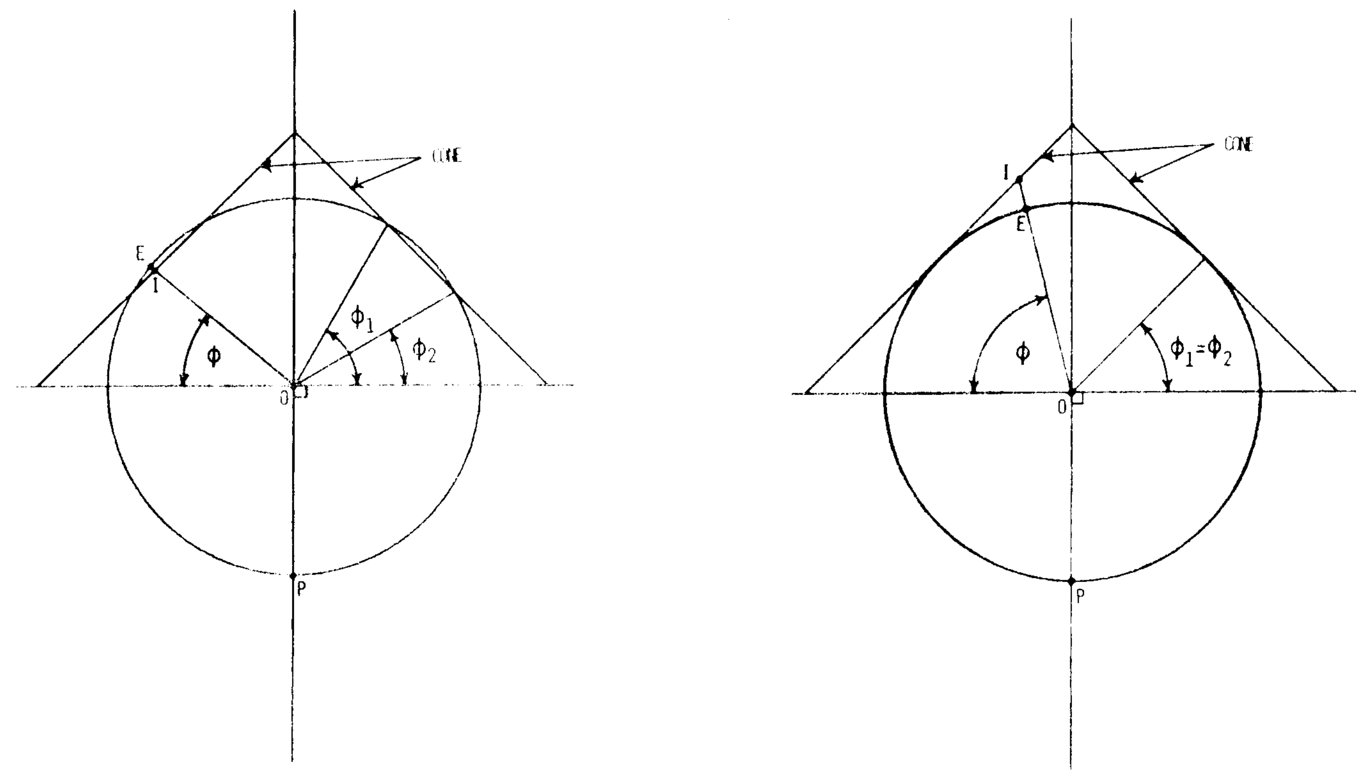
$$y = a \cos\phi_1 \; \ell n[\tan \tfrac{1}{2}(\phi+\tfrac{1}{2}\pi)] = a \cos\phi_1 \; \ell n \left(\frac{1+\sin\phi}{\cos\phi}\right) . \tag{2.11}$$

In these equations λ is longitude and λ_o is the reference longitude. At AFGWC, λ_o is 0° for Mercator projections. Also, ϕ is latitude, $\cos\phi_1$ (= $\cos\phi_2$) is the cosine of the true latitude, $\pi = 3.14159...$, and a is the radius of the earth. By eqs. (2.10) and (2.11), x increases to the east and y increases to the north.

2.6 LAMBERT CONFORMAL PROJECTIONS AND MAPS

Lambert conformal projections of the secant variety are occasionally used at AFGWC for areas centered in the middle latitudes, especially when the area has a longer east-west extent than north-south. To aid in the general understanding of the characteristics of the Lambert conformal projection, in the discussion to follow we project the earth's surface onto a normally positioned cone that intersects the earth at standard latitudes ϕ_1 and ϕ_2 (Fig. 2.11a). Then we shrink or stretch the resultant in both the north-south and east-west directions. In actuality, however, the secant Lambert conformal projection is derived mathematically (the conventional generation of the Goussinsky classification scheme). A Lambert conformal projection of the tangent variety (true at $\phi_1 = \phi_2$) on the other hand, can be constructed semi-geometrically.

In the following discussion, equations for the secant projection and map will be presented. Equations for the tangent case are obtained with $\phi_1 = \phi_2$, except as noted in Section 2.6.2.



a) b)

Figure 2.11. Side view of the geometry for projecting the earth onto a cone with apex over the North Pole: a) secant variety (standard latitudes ϕ_1 = 60°N, ϕ_2 = 30°N) and b) tangent variety ($\phi_1 = \phi_2$ = 45°N). The South Pole is designated by P and the earth's center by O. The point E at latitude ϕ on the earth's surface is projected onto point I on the geometric figure, the cone.

2.6.1 GENERATION OF THE SECANT LAMBERT CONFORMAL MAP

The secant Lambert conformal map can be formed in the following manner. First, a cone, which is the geometric figure for this projection, is positioned so that its apex is directly over one of the earth's poles and its sides pass through standard latitudes ϕ_1 and ϕ_2 (Fig. 2.11a). Next, for each latitude ϕ the surface of the earth (point E) is projected onto the cone (the geometric figure) at point I by drawing a ray from the center of the earth (point O) (Fig. 2.11a). After the desired points on the earth's surface are projected, the resultant is shrunk or stretched in both the north-south and east-west directions to obtain an image surface that is conformal. Then the image surface is developed into the two-dimensional image plane by cutting the image surface along a meridian and unrolling it. Finally, the image plane is reduced to a map of manageable size by means of the map scale μ.

The image plane and map (Fig. 2.12) are conformal everywhere except at the pole. Meridians are depicted as straight lines converging at the pole. Latitude circles appear as arcs of concentric circles centered at the pole. In addition, straight lines on the image plane and map approximate great circles. For many meteorological applications, only that part of the projection in the region of interest is displayed.

2.6.2 LAMBERT CONFORMAL IMAGE SCALE

For secant Lambert conformal projections true at Ql and Q2, image scale σ is a function of latitude and is given by

$$\sigma(\phi) = \begin{cases} \dfrac{\cos\phi_1}{\cos\phi}\left(\dfrac{\tan\frac{1}{2}(90^\circ H-\phi)}{\tan\frac{1}{2}(90^\circ H-\phi_1)}\right)^n , \\[2ex] \left(\dfrac{\cos\phi_1}{\cos\phi}\right)^{1-n}\left(\dfrac{1+H\sin\phi_1}{1+H\sin\phi}\right)^n , \\[2ex] \left(\dfrac{\cos\phi_2}{\cos\phi}\right)^{1-n}\left(\dfrac{1+H\sin\phi_2}{1+H\sin\phi}\right)^n , \end{cases} \tag{2.12}$$

where

$$n = \frac{\ell n\left(\dfrac{\cos\phi_2}{\cos\phi_1}\right)}{\ell n\left(\dfrac{\tan\frac{1}{2}(90^\circ H-\phi_2)}{\tan\frac{1}{2}(90^\circ H-\phi_1)}\right)} \tag{2.13}$$

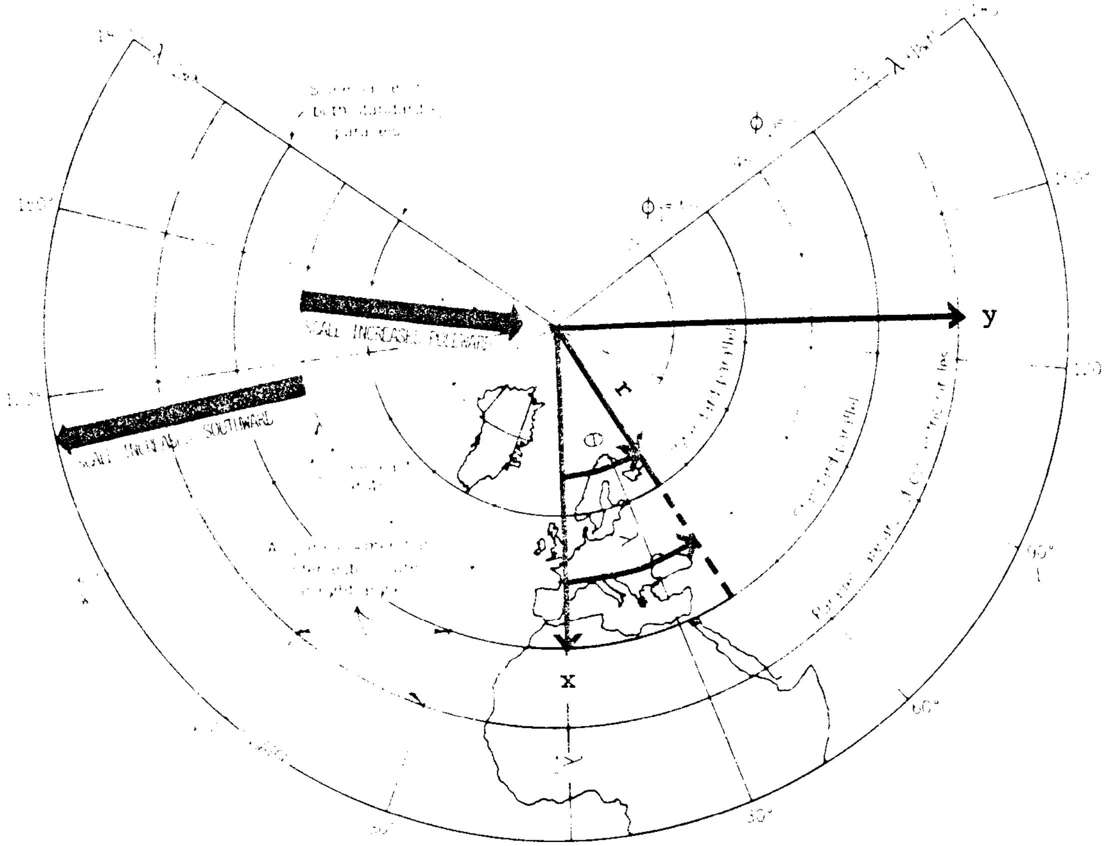


Figure 2.12. Lambert conformal map with standard latitudes 60^{o}N/30^{o}N and with a reference iongitude λ_o of 0^{o} (after © Strahler, 1969; John Wiiey and Sons, Inc., Publishers). Therefore, n = 0.7156 by eq. (2.13). The image-plane Cartesian coordinates (x,y) (see Section 2.6.3) and the image-plane polar coordinates (r,θ) are included. Longitude λ is related to azimuth θ by eq. (2.18).

GENERATION OF AFTAC DATA

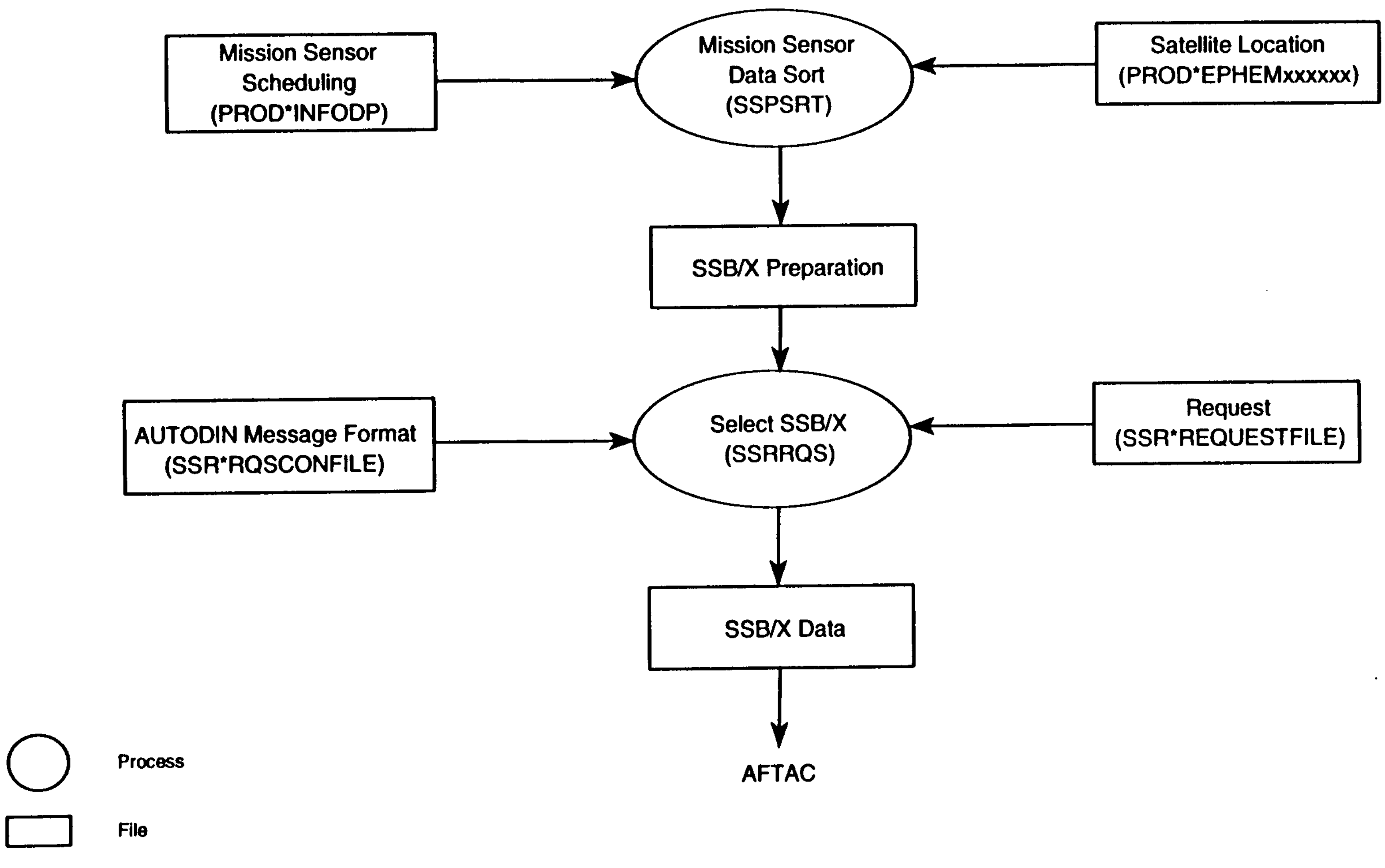


FIGURE 9

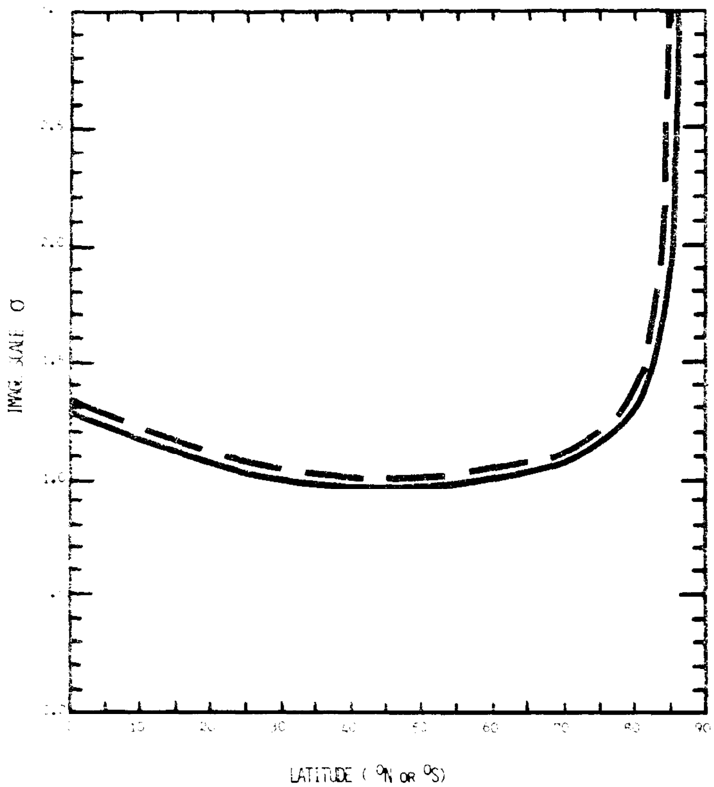


Figure 2.13. The latitudinal variation of image scale σ for Lambert conformal projections true at 30/60°N or °S (solid line) and 45°N or °S (dashed line). Not plotted is the image scale for these projections extending into the opposite hemisphere.

SECTION 3. GRIDS

The advent of high-speed digital computers in the 1940s offered new opportunities in meteorology. For the first time it became feasible on a near-real-time basis to produce numerical weather forecasts based on the hydrodynamic equations. In addition, computers could be used to display and analyze large quantities of data, thereby reducing the amount of time and effort required by the meteorologist to assimilate meteorological information.

To facilitate manipulation of data on these computers, grid systems were developed. The term grid may be defined as an array of points. For meteorological applications these points are located at the intersections of uniformly spaced parallel and perpendicular lines (Fig. 3.1). In meteorology (as well as other fields such as geography and navigation), this array is given meaning when it is superimposed on a map (Fig. 3.2) so that individual grid points represent points on the surface of the earth. An indexing convention called the (I,J) indexing convention has been developed to identify individual grid positions. An example of the (I,J) indexing convention used for most grids at AFGWC is shown in Fig. 3.3.

Of course, observations of the atmosphere normally are not taken at grid points, but instead at irregularly spaced points. The process whereby the data are interpolated from the observational points to the grid points is called analysis. At AFGWC analysis of meteorological data is performed by numerous models--the Hough global spectral analysis model (HUFANL) and the Three-dimensional Nephanalysis Model (3DNEPH) are important examples. At AFGWC, world-wide observations from land surface stations and radiosondes, for example, are stored individually in data bases separate from the gridded data. (Appendix A provides the numbered geographic regions in which the observations are located globally by the World Meteorological Organization (WMO) and are stored in the AFGWC data base.)

At AFGWC, reference grids have been defined to provide a basis for the many grids used. For a given image surface (such as a Northern Hemispheric or Southern Hemispheric polar stereographic projection), a common geographical region is specified for all reference grids. The shortest distance between adjacent grid points on the polar stereographic Whole-mesh Reference Grids is referred to as the whole-mesh grid length. All finer-resolution grids superimposed on a given image surface are defined relative to the Whole-mesh Reference Grids. For example, distance between half-mesh grid points is one-half the distance between whole-mesh grid points; distance between quarter-mesh grid points is one-fourth that between whole-mesh grid points. The relationship between a whole-mesh grid and its half-mesh and quarter-mesh counterparts is shown in Fig. 3.4.

A number of smaller-area grids that are subsets of either the Whole-mesh Reference Grids or a finer-mesh version of these reference grids are also defined. These area1 subsets, which cover only a specific area of interest, are used to economize computer resources.

In this section, AFGWC grid systems will be described. Included are polar stereographic, Mercator, and latitude-longitude grid systems. For each of these three systems a description is given for the reference grid, finer-mesh versions, and area1 subsets, when applicable. This information has been discussed, in part, in publications by Headquarters Third Weather Wing (1962), Johnson (1977), and Headquarters AFGWC (1978).

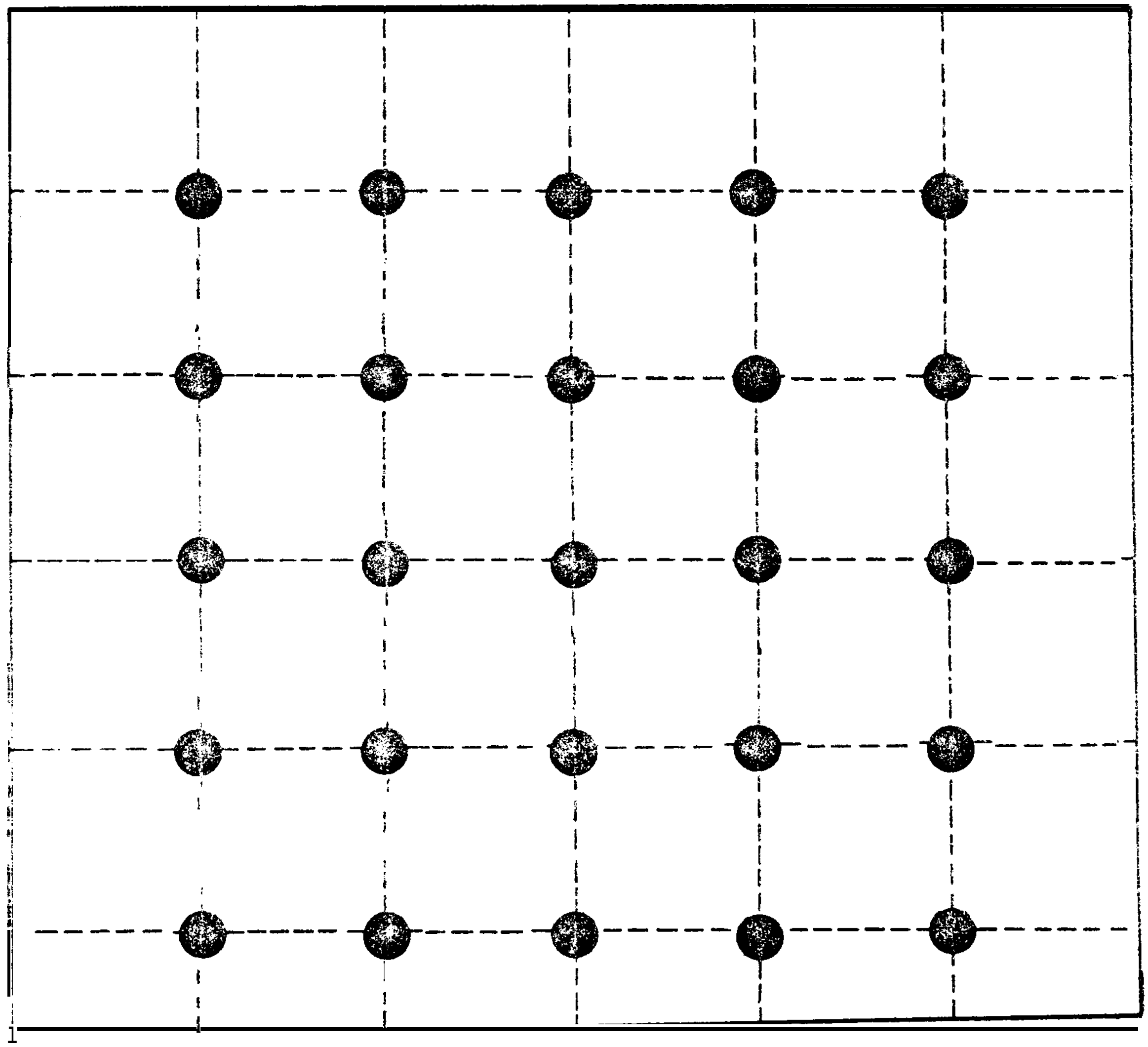


Figure 3.i. Example of a grid--an array of points located at the intersections of uniformly spaced parallel and perpendicular lines.

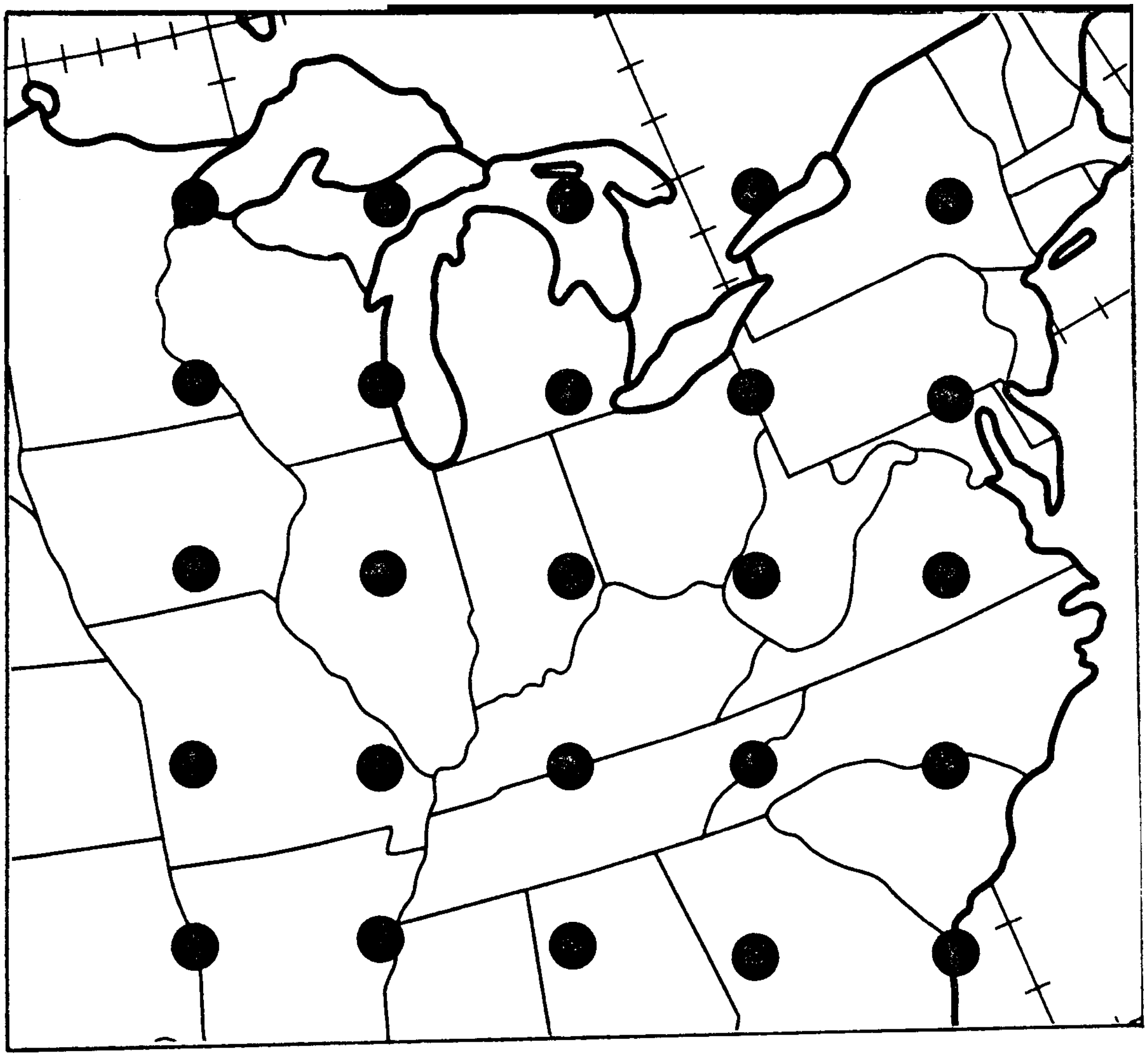


Figure 3.2. A grid superimposed on a map.

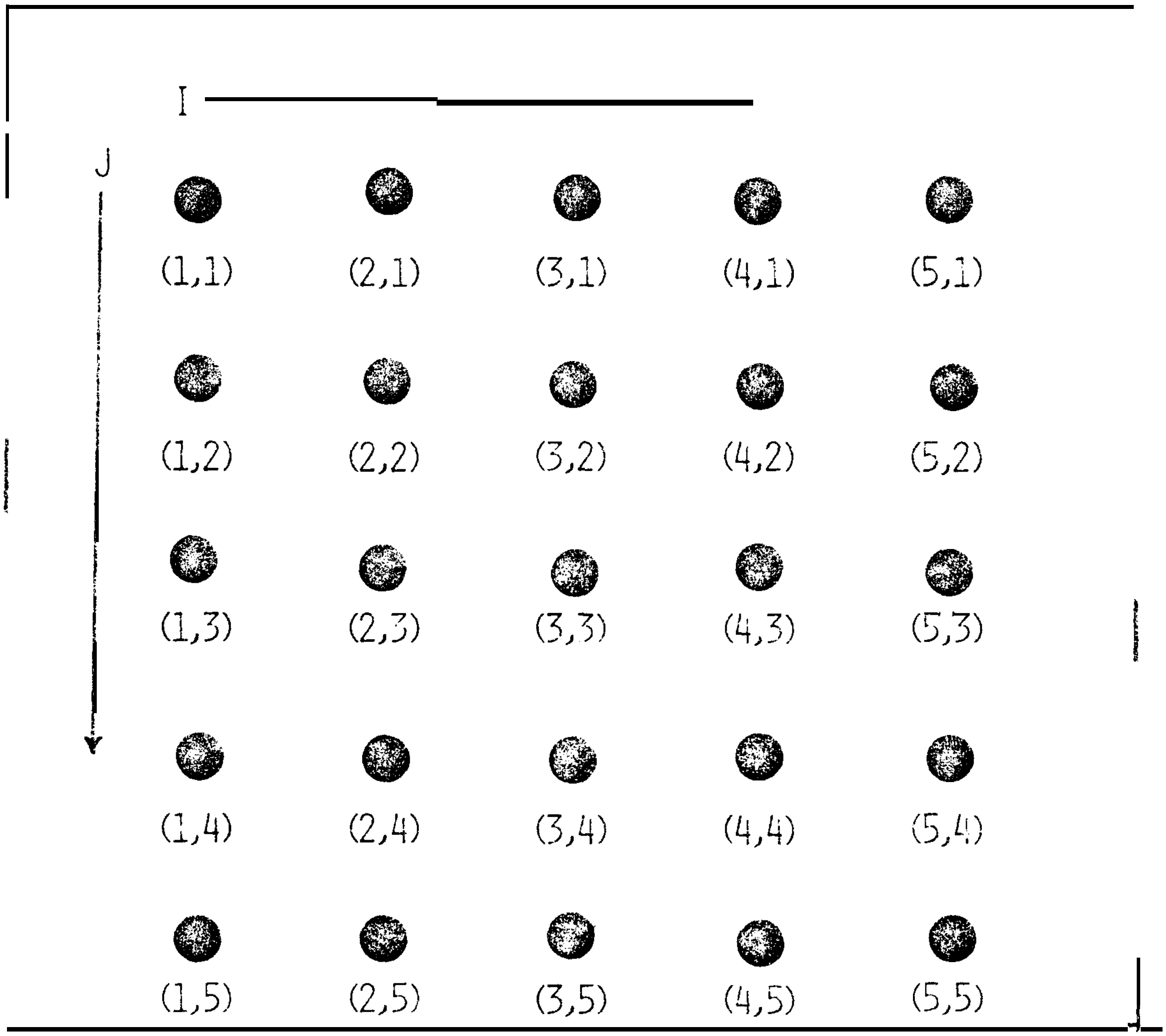


Figure 3.3. An example of the (I,J) indexing convention used for most grids at AFGWC. In this example, the column index I increases from left to right, whereas the row index J increases from top to bottom.

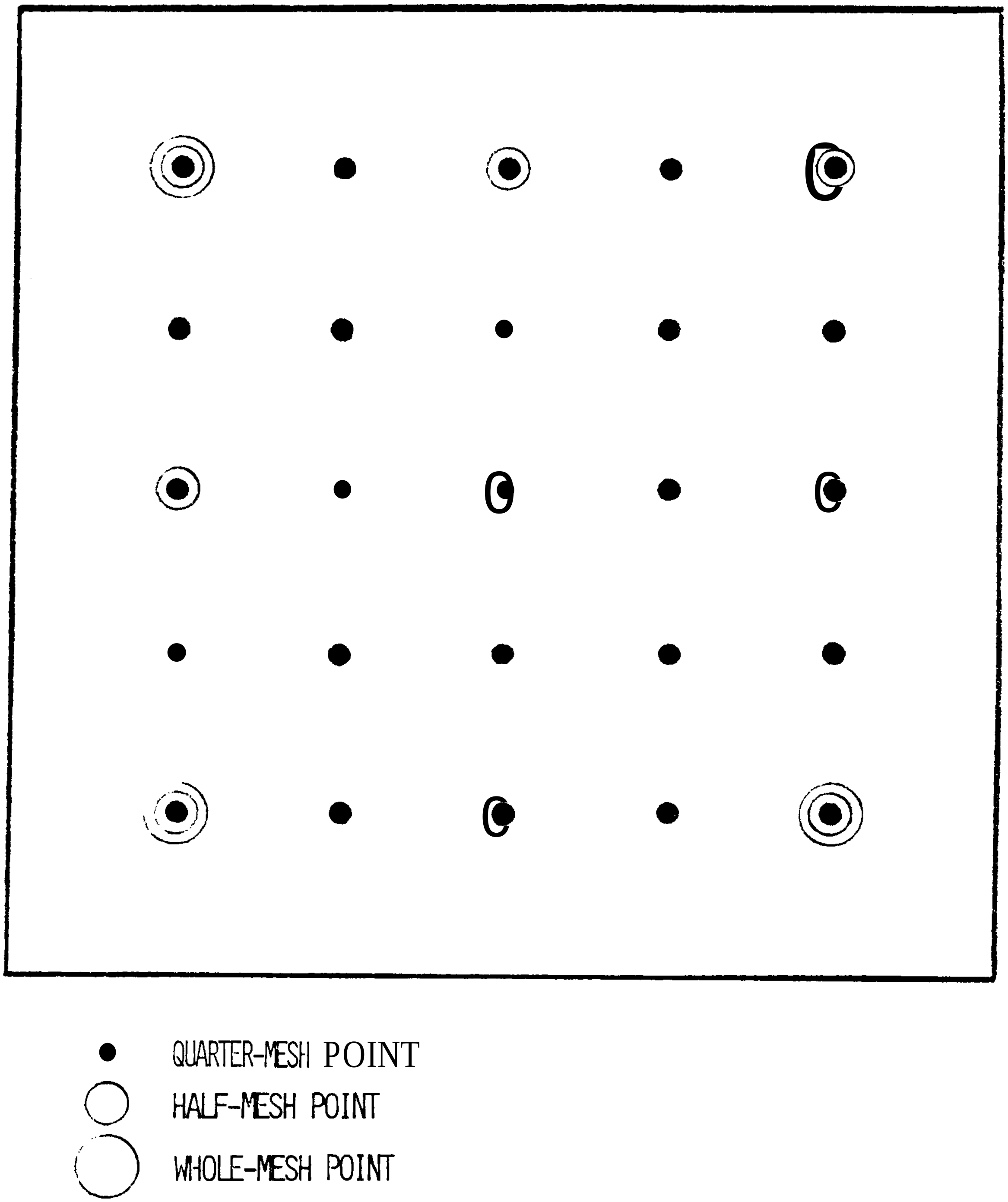


Figure 3.4. Relationship between whole-mesh, half-mesh, and quarter-mesh grid points. Note that each whole-mesh point is also a half-mesh and quarter-mesh point. Similarly, each half-mesh point is also a quarter-mesh point.

It is important to note on the following figures that lines establishing boundaries of the various grids pess through the grid points, not between them.

3.1 POLAR STEREOGRAPHIC GRIDS

Polar stereographic grids are used extensively at AFGWC for numeric21 computations and automated displays. As the name implies, these grids are based on polar stereographic projections. Two reference domains have been defined at AFGWC--one centered on the Northern Hemisphere and the other centered on the Southern Hemisphere. The domains are based on secant polar stereographic projections true at 60°N and °S, respectively. (The secant polar stereographic projection is discussed in Section 2.4). For both the Northern and Southern hemispheric areas, reference grids of various resolutions have been defined. Polar stereographic grids for numerical analysis and forecasting at AFGWC are subsets of these reference grids.

3.1.1 GENERALIZED EQUATIONS

For polar stereographic projections we define a whole-mesh grid as one in which the grid points are exactly 381 km apart at 60°N or °S on the earth's surface. Such a grid could be constructed, for example, by superimposing an array of points one-half inch apart on a polar stereographic map with map scale 1:30,000,000 and true at 60°N (or °S). In this Technical Note we represent the distance 381 km by d_o; that is,

$$d_o = 381 \text{ km} \quad . \tag{3.1}$$

The distance between whole-mesh grid points on the earth's surface is a function of latitude and is named the whole-mesh grid length (or grid interval, grid increment, grid unit, etc.). An increasingly popular name for this unit is the bedient (Stackpole, 1978), which is named for H. A. Bedient, who was instrumental in developing the map and grid systems of the Joint Numerical Weather Prediction Unit in the 1950s. Other grid lengths are simply fractions of the whole-mesh grid length--half mesh, quarter mesh, eighth mesh, and sixty-fourth mesh, for examples.

The distance d_i between grid points on the image surface is given by

$$d_i = d_o \, S \, M \quad , \tag{3.2}$$

where M is the mesh factor, which is defined as the ratio of the grid length to the whole-mesh grid length on the image plane. (Therefore, for a whole-mesh grid, M = 1, and for a half-mesh grid, M = 1/2.) The scaling parameter S, where

$$S = \frac{1 + H \sin \phi_o}{1 + \sin 60^\circ} \quad , \tag{3.3}$$

is defined so that whole-mesh grid points are exactly 381 km apart at 60°N (or °S) on the earth's surface, regardless of the standard latitude ϕ_o. For applications at AFGWC, ϕ_o is 60°N (and °S) so that S = 1. H designates the hemisphere of the projection (see eq. (2.3)) and d_o equals 381 km.

By definition of image scale σ (Section 2.2) and eqs. (2.2) and (3.2), the distance de between grid points on the earth's surface is

$$d_e = \frac{d_i}{\sigma} = \frac{d_o S M}{\sigma} \quad , \tag{3.4}$$

where

$$\sigma(\phi) = \frac{1 + H \sin \phi_0}{1 + H \sin \phi} \quad , \tag{3.5}$$

which is valid for both Northern and Southern Hemispheric projections. By substitution of eqs. (3.3) and (3.5) into eq. (3.41, d_e can be shown to be independent of standard latitude. For a whole-mesh grid (M = 1) on a Northern Hemispheric map (H = +1), d_e is 381 km at 60°N, as expected. A plot of d_e as a function of latitude is shown in Fig. 3.5 for a whole-mesh grid.

By the definition of map scale μ (Section 2.2) and eq. (3.21, the distance dm between grid points on the map is given by

$$d_m = \mu d_i = \mu d_o S M \quad . \tag{3.6}$$

Thus, for a whole-mesh (M = 1) polar stereographic grid with map scale μ = 1:15,000,000 and true at 600N or °S, d_m = 2.54 cm = 1 inch.

The (I,J) indexing convention for the grids identifies positions relative to grid points. The convention is left-handed for the polar stereographic grids: the column index I increases from 1 on the left of the grid toward the right, whereas the row index J increases from 1 at the top of the grid toward the bottom. Figs. 3.6 and 3.7 provide examples for the Northern Hemispheric and Southern Hemispheric Whole-mesh Reference Grids, respectively.

The grid-point Cartesian coordinates (X,Y) for a point are expressed in multiples of grid length di (which is a function of mesh factor M) from the pole according to

$$X = I - I_P \quad , \tag{3.7}$$

$$Y = -H \quad (J - J_p) \quad , \tag{3.8}$$

where I_p and J_p are the I and J coordinates, respectively, of the pole on which the projection is centered. The point (I_p,J_p) may actually be outside the domain of the grid, as with the U.S. Boundary-layer Model grid, for example. H is +1 for Northern Hemispheric grids and -1 for Southern Hemispheric grids (eq. 2.3). Eqs. (3.7) and (3.8) are valid for any point on the earth. Examples for the Northern Hemispheric and Southern Hemispheric Whole-mesh Reference Grids are given in Figs. 3.6 and 3.7, respectively.

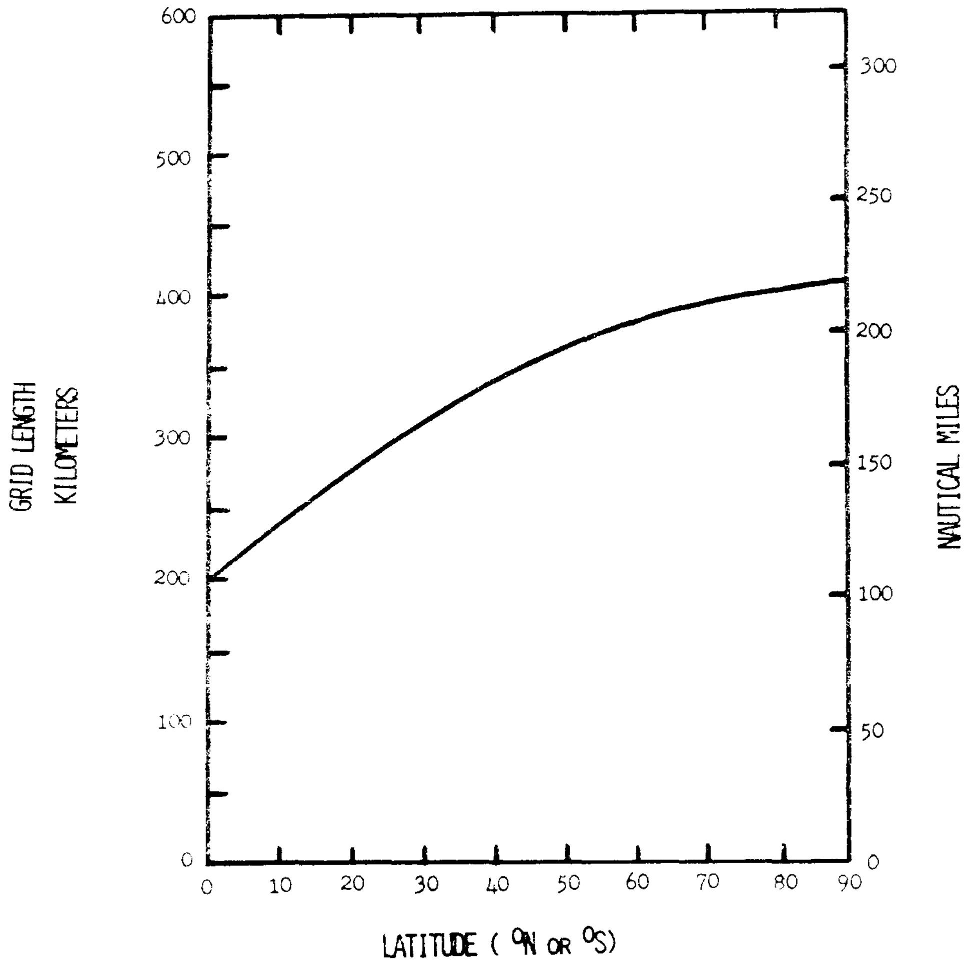


Figure 3.5. The grid length de on the earth's surface as a function of latitude ɔ for a whole-mesh grid on a Northern Hemispheric or Southern Hemispheric polar stereographic projection.

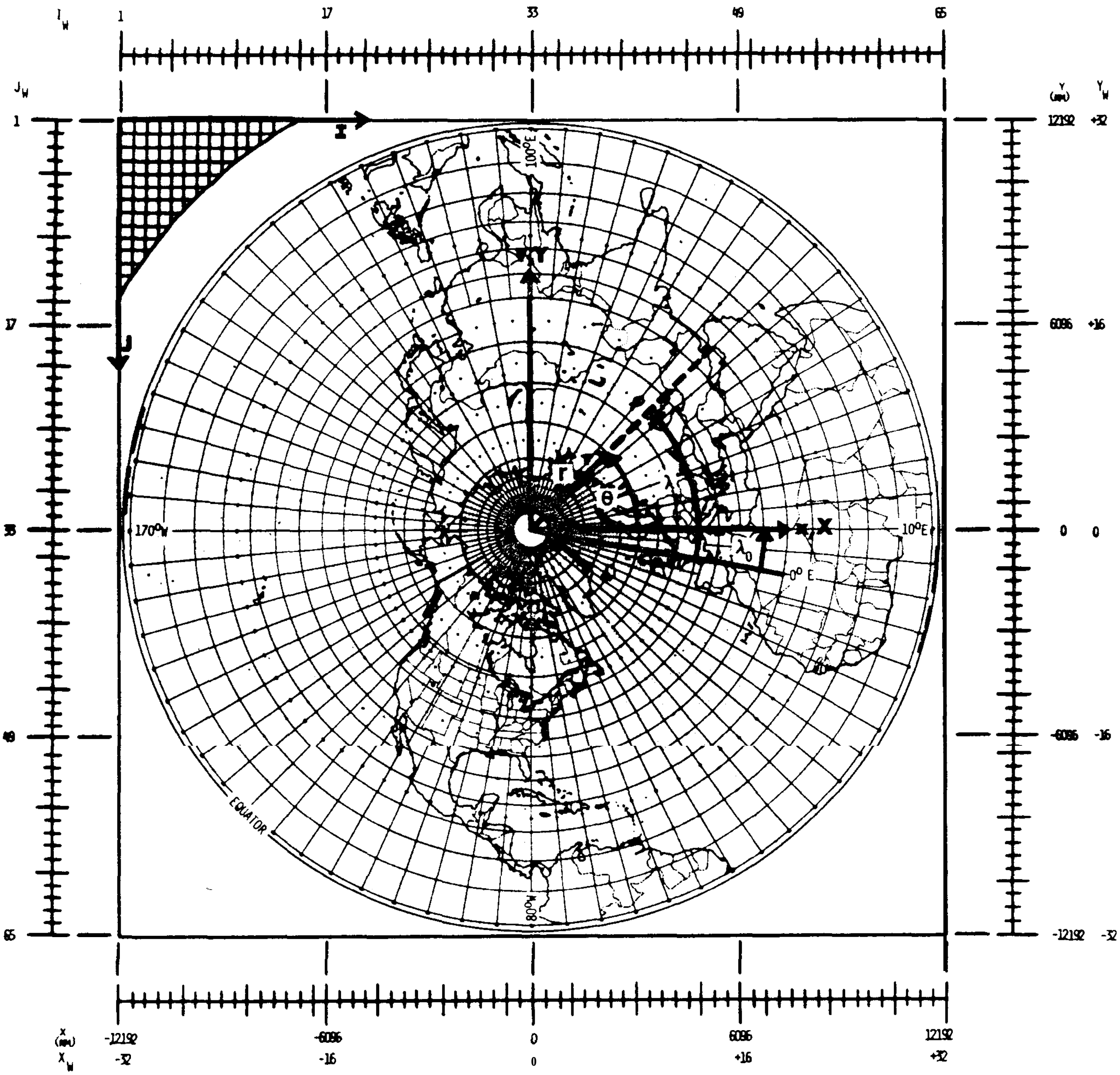


Figure 3.6. The Northern Hemispheric Whole-mesh Reference Grid. The domain for this polar stereographic projection extends into the Southern Hemisphere, which is not plotted. Also included are the axes for the (I,J) indexing convention, the image-plane Cartesian coordinates (x,y), the grid-point Cartesian coordinates (X,Y), and the image-plane polar coordinates (r, θ). The w subscripts indicate values for the whole-mesh grid. The longitude is λ and λ_0 is the reference longitude (10°E at AFGWC). The distances for the (x,y) coordinates are, by definition, with respect to the image plane. The whole-mesh grid spacing is displayed in the upper-left corner.

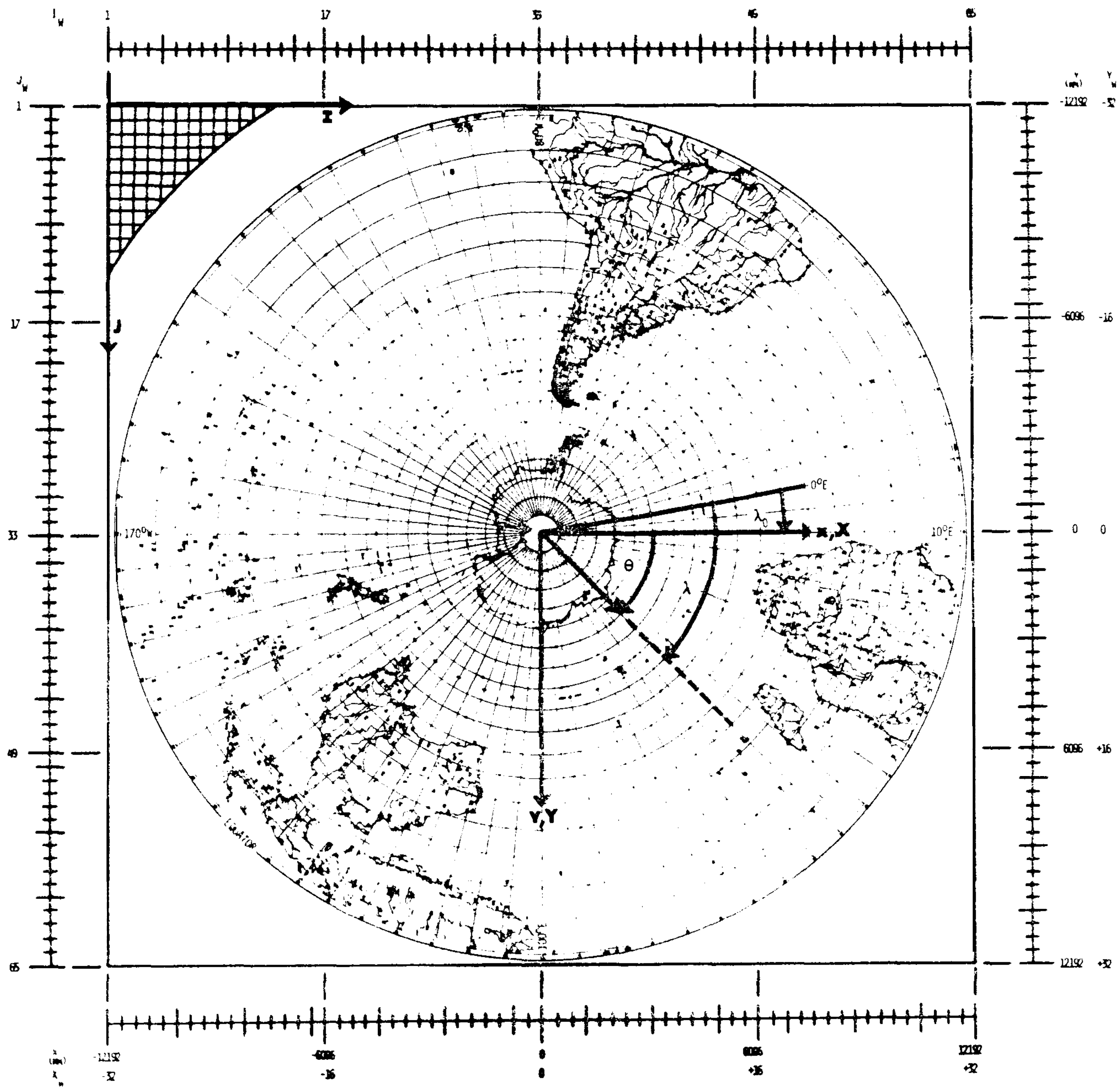


Figure 3.7. The Southern Hemispheric Whole-mesh Reference Grid. The domain *for* this polar stereographic projection extends into the Northern Hemisphere, which is not plotted. Also included are the axes for the (I,J) indexing convention, the image-plane Cartesian coordinates (x,y), the grid-point Cartesian coordinates (X,Y), and the image-plane polar coordinates (r,θ). The w subscripts indicate values for the whole-mesh grid. The longitude is A and λ_0 is the reference longitude (10°E at AFGWC). The distances for the (x,y) coordinates are, by definition, with respect to the image plane. The whole-mesh grid spacing is displayed in the upper-left corner.

Image-plane Cartesian coordinates (x,y), discussed in Section 2.4.3 (eqs. (2.4) and (2.5)) and plotted in Figs. 3.6 and 3.7, can be calculated from grid-point Cartesian coordinates (X,Y) by multiplying each (X,Y) value by d_i, the distance between grid points on the image plane (see eq. (3.2)). That is,

$$x = d_i X \quad , \tag{3.9}$$

$$y = d_i Y \quad . \tag{3.10}$$

From eqs. (2.2)-(2.5), (3.2), (3.9), (3.10), and trigonometric identities, the latitude of any grid point may be calculated as follows:

$$\phi = H \arcsin\left\{\frac{\left(\frac{a}{d_o SM}\right)^2 \left(1 + H \sin\phi_o\right)^2 - \left(X^2 + Y^2\right)}{\left(\frac{a}{d_o SM}\right)^2 \left(1 + H \sin\phi_o\right)^2 + \left(X^2 + Y^2\right)}\right\} \quad . \tag{3.11}$$

In the preceding equation ϕ_o is the standard latitude (60°N or $^\circ$S at AFGWC); a represents the radius of the earth; (X,Y) are the grid point's Cartesian coordinates as defined in eqs. (3.7) and (3.8); M is the mesh factor; and H, d_o, and S are given by eqs. (2.3), (3.1), and (3.3), respectively. The arcsin function has principle values from -90° to $+90^\circ$.

From eqs. (2.4), (2.51, (3.9), and (3.10), the longitude of any grid point can be calculated using the arccosine function:

$$\lambda = \begin{cases} \lambda_o + \arccos\left(\dfrac{X}{\left(X^2 + Y^2\right)^{\frac{1}{2}}}\right) \quad , & Y \geq 0 \quad , \\[2ex] \lambda_o - \arccos\left(\dfrac{X}{\left(X^2 + Y^2\right)^{\frac{1}{2}}}\right) \quad , & Y \leq 0 \quad , \\[2ex] \lambda_o \quad \text{(by definition)} \quad , & X = Y = 0 \quad . \end{cases} \tag{3.12}$$

Once again, X and Y are defined in eqs. (3.7) and (3.8). Note that λ_o, the reference longitude, is 10°E at AFGWC. The arccosine function has principle values from 0° to 180°.

The (I,J) coordinates of any point may be expressed in terms of the point's latitude and longitude according to

$$I = I_p + R_M \cos(\lambda-\lambda_o) \quad , \tag{3.13}$$

$$J = J_p - H R_M \sin(\lambda-\lambda_o) \quad , \tag{3.14}$$

where

$$R_M = \frac{a\ \sigma\ \cos\phi}{d_i} = \frac{a\ \sigma\ \cos\phi}{d_o\ S\ M} \tag{3.15}$$

R_M is the radial distance on the image piane between the pole and latitude ϕ in multiples of grid length di (see eq. (3.2)). The radius of the earth is represented by $\underline{a}$, the mesh factor is M, longitude is A, reference longitude is λ_o, the p subscripts designate the coordinates of the pole, d_o is 381 km, and σ is given by eq. (2.2), H by eq. (2.3), di by eq. (3.2), and S by eq. (3.3).

Indices (I,J) of one grid may be converted to indices (I',J') of any other grid by

$$I' = I'_p + \frac{M}{M'} (I - I_p) \quad , \tag{3.16}$$

$$J' = J'_p + \frac{M}{M'} (J - J_p) \quad . \tag{3.17}$$

Here M and M' are the mesh factors for the grids with points (I,J) and (I',J'), respectively. These two equations appiy to any two polar stereographic grids projected on the same hemisphere.

3.1.2 POLAR STEREOGRAPHIC REFERENCE GRIDS

Polar stereographic reference grids exist for the Northern and Southern Hemispheres at resoiutions to provide weather support from the synoptic scale down to the mesoscale. For a polar stereographic projection centered on a given hemisphere, the domains of all the reference grids are the same; they include the entire hemisphere on which the grid is centered and, at the corners of the grids, extend well beyond the Equator into the opposite hemisphere. (Fig. 3.6 provides an example using the Northern Hemispheric Whole-mesh Reference Grid.)

3.1.2.1 THE NORTHERN HEMISPHERIC WHOLE-MESH REFERENCE GRID

The Northern Hemispheric Whole-mesh Reference Grid (sometimes called the Northern Hemispheric Whole-Mesh Super Grid) is a 65x65 whole-mesh grid based on a Northern Hemispheric polar stereographic map with standard latitude 600N (Fig. 3.6). For a map scale of 1:30,000,000, the grid can be constructed by superimposing a 65x65 array of points on a map with one-half inch between points. For the Northern Hemispheric Whole-mesh Reference Grid, eqs. (3.1)-(3.15) apply with the parameter values given in Table 3.1.

The (I,J) indexing convention for the Northern Hemispheric Whole-mesh Reference Grid is shown in Fig. 3.6. The column index I varies from 1 on the left of the grid to 65 on the right, whereas the row index J varies from 1 at the top of the grid to 65 at the bottom. Column 33 (I = 33) coincides with the 100°E and 800W meridians; row 33 (J = 33) coincides with the 170°W and 10°E meridians. The North Pole is represented by point (33,33).

In Fig. 3.6, the (whole-mesh) grid-point Cartesian coordinate system (X,Y) defined for the Northern Hemispheric polar stereographic projection is superimposed on the Northern Hemispheric Whole-mesh Reference Grid with the origin of the system at the North Pole. The positive X axis is oriented in the direction of increasing I and the positive Y axis in the direction of <u>decreasing</u> J. The (X,Y) coordinate system serves as the frame of reference for orientation of gridded wind components: u and v components are <u>positive</u> in the directions of <u>increasing</u> X and Y, respectively.

Table 3.1. Parameters for the Northern Hemispheric Whole-mesh Reference Grid.

PARAMETER	DESCRIPTION
$H = +1$	Northern Hemispheric projection
$\phi_o = 60^o N$	standard latitude
$M = 1$	whole-mesh grid
$d_e(\text{at } \phi = 60^o N) = 381$ km	grid length at 600N
$1 \le I \le 65$	grid points in the I direction
$1 \le J \le 65$	grid points in the J direction
$(I_p, J_p) = (33,33)$	polar location (North Pole)

3.1.2.2 THE SOUTHERN HEMISPHERIC WHOLE-MESH REFERENCE GRID

The Southern Hemispheric Whole-mesh Reference Grid (also called the Southern Hemispheric Whole-mesh Super Grid) is a 65x65 whole-mesh grid based on a Southern Hemispheric polar stereographic map true at 60°S (Fig. 3.7). For a map scale of 1:30,000,000, the grid can be constructed by superimposing a 65x65 array of points on a map with one-half inch between points. For the Southern Hemispheric Whole-mesh Reference Grid, eqs. (3.1)-(3.15) apply with the parameter values given in Table 3.2.

The (I,J) indexing convention is shown in Fig. 3.7. I extends from 1 on the left of the grid to 65 on the right and J extends from 1 on the top of the grid to 65 at the bottom. Column 33 (I = 33) coincides with the 100°E and 80°W meridians; row 33 (J = 33) coincides with the 170°W and 10°E meridians. The South Pole is located at grid point (33,33).

In Fig. 3.7, the (whole-mesh) grid-point Cartesian coordinate system (X,Y) for the Southern Hemispheric polar stereographic projection is superimposed on the Whole-mesh Reference Grid for that hemisphere. The origin is placed at the South Pole with the positive X axis oriented in the direction of increasing I and the positive Y axis oriented in the direction of increasing J. As with the Northern Hemispheric grid, this coordinate system serves as the frame of reference for orientation of gridded wind components. The u component is <u>positive</u> in the direction of <u>increasing</u> X and, in contrast to the Northern Hemispheric convention, the v component is <u>positive</u> in the direction of <u>decreasing</u> Y.

Table 3.2. Parameters for the Southern Hemispheric Whole-mesh Reference Grid.

PARAMETER	DESCRIPTION
$H = -1$	Southern Hemispheric projection
$\phi_o = 60°S$	standard latitude
$M = 1$	whole-mesh grid
$d_e(\text{at } \phi = 60°S) = 381$ km	grid length at 60°S
$1 \leq I \leq 65$	grid points in the I direction
$1 \leq J \leq 65$	grid points in the J direction
$(I_p, J_p) = (33,33)$	polar location (South Pole)

3.1.2.3 FINER-MESH POLAR STEREOGRAPHIC REFERENCE GRIDS

In representing the atmosphere with a whole-mesh grid, approximation results because smaller-scale motions cannot be correctly represented. In fact, the shortest wavelength resolvable on any grid is equal to twice the distance between its grid points. Also, wavelengths shorter than about four grid lengths are handled poorly by numerical prediction models (Haltiner and Williams, 1980). As mentioned previously, the whole-mesh grid length is approximately 381 km (exactly 381 lan at 600N (or OS)) on the earth's surface. Consequently, wavelengths shorter than about 1600 km are poorly forecast using a whole-mesh grid and wavelengths shorter than about 800 km are not represented at all.

Because many meteorological applications at AFGWC are concerned with scales of motion much smaller than either 1600 or 800 km, finer-resolution grids had to be developed. With the whole-mesh reference grid as a standard, a family of finer-mesh reference grids that cover the same total area as the Whole-mesh Reference Grid has been developed for both the Northern and Southern Hemispheres. Figs. 3.8 and 3.9 for the Northern and Southern Hemispheres, respectively, include reference grids at half mesh, quarter mesh, eighth mesh, and sixty-fourth mesh. As the names imply, distance between grid points on these finer-mesh grids is defined relative to the reference whole-mesh grid length. For instance, at a given latitude, distance between adjacent half-mesh grid points is one-half the distance between adjacent whole-mesh points. (For example, at 600N (or OS), the whole-mesh grid length is 381 km, so that the half-mesh grid length is 190.5 km). The AFGWC reference grids are listed by mesh size (that is, whole-mesh, half-mesh, etc.) in Table 3.3. Also included in the table are the mesh factor M, which is the ratio of the grid length to the whole-mesh grid length; the array size, where IxJ is the total number of grid points; (I_p,J_p), which are the (I,J) indices of the pole; and the distance d_e between grid points given in both kilometers and nautical miles. The basic parameters for the Finer-mesh Polar Stereographic Reference Grids, as well as the Whole-mesh Polar Stereographic Reference Grids, are summarized in Table 3.4.

Table 3.3. The Polar Stereographic Reference Grids.

MESH SIZE	MESH FACTOR (M)	ARRAY SIZE IxJ = TOTAL NUMBER OF POINTS		GRID POINT LOCATION OF THE POLE (I_p,J_p)	DISTANCE d_e BETWEEN GRID POINTS AT 600N (OR OS): KILOMETERS	NAUTICAL MILES*
Whole	1	65x65 =	4,225	(33,331	381.	205.72354
Half	1/2	129x129 =	16,641	(65,65)	190.5	102.86177
Quarter	1/4	257x257 =	66,049	(129,129)	95.25	51.43088
Eighth	1/8	513x513 =	263,169	(257,257)	47.625	25.71544
Sixty-fourth	1/64	4097x4097 =	16,785,409	(2049,2049)	5.953125	3.21443

*based on the international nautical mile for which 1 nm = 1852 m.

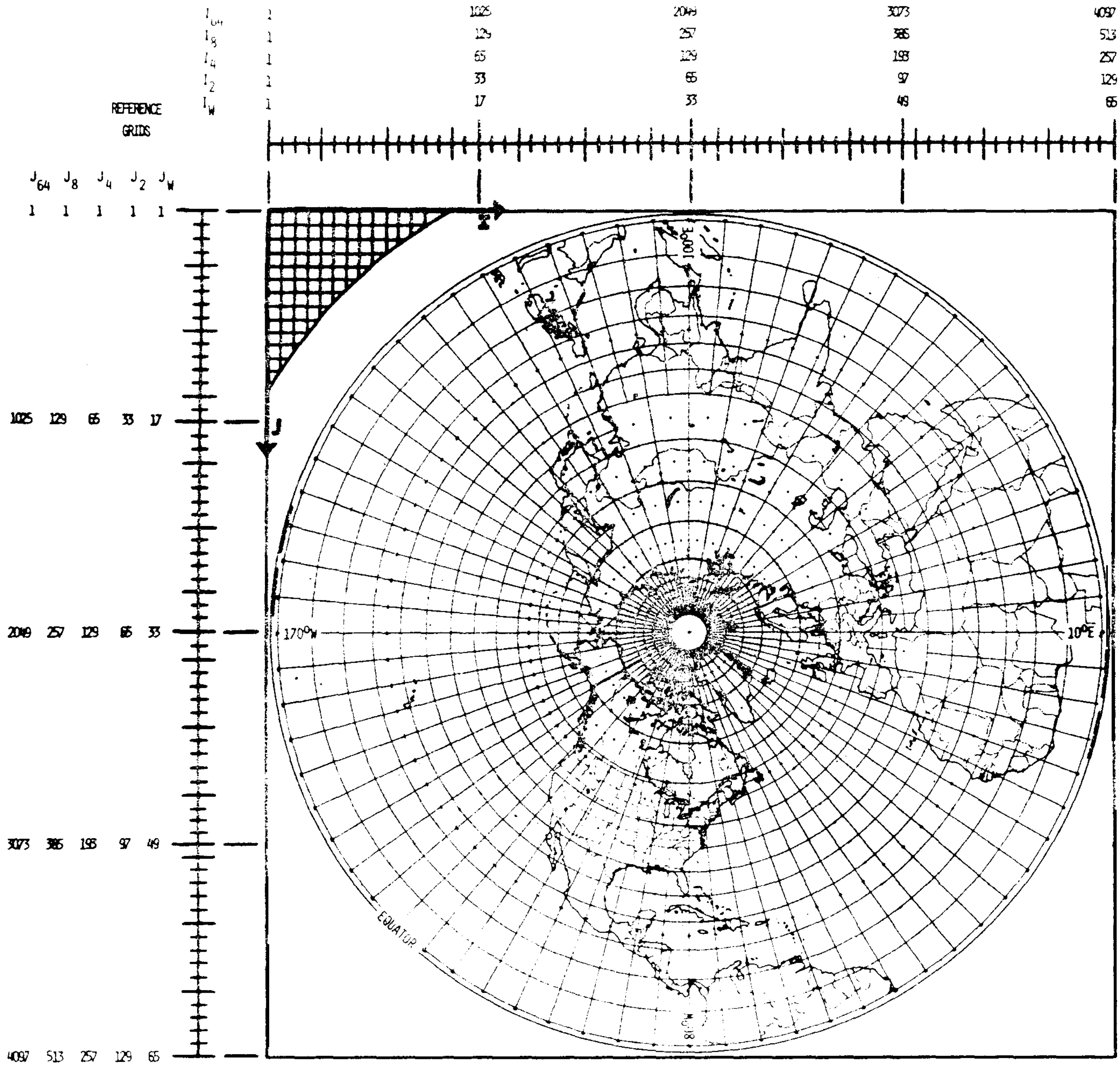


Figure 3.8. The (I,J) indices for the Whole-mesh and Finer-mesh Reference Grids of the Northern Hemisphere. The subscripts denote whole-mesh (I_w,J_w), half-mesh (I_2,J_2), quarter-mesh (I_4,J_4), eighth-mesh (I_8,J_8), and sixty-fourth-mesh (I_{64},J_{64}) indices. The whole-mesh grid spacing is displayed in the upper-left corner.

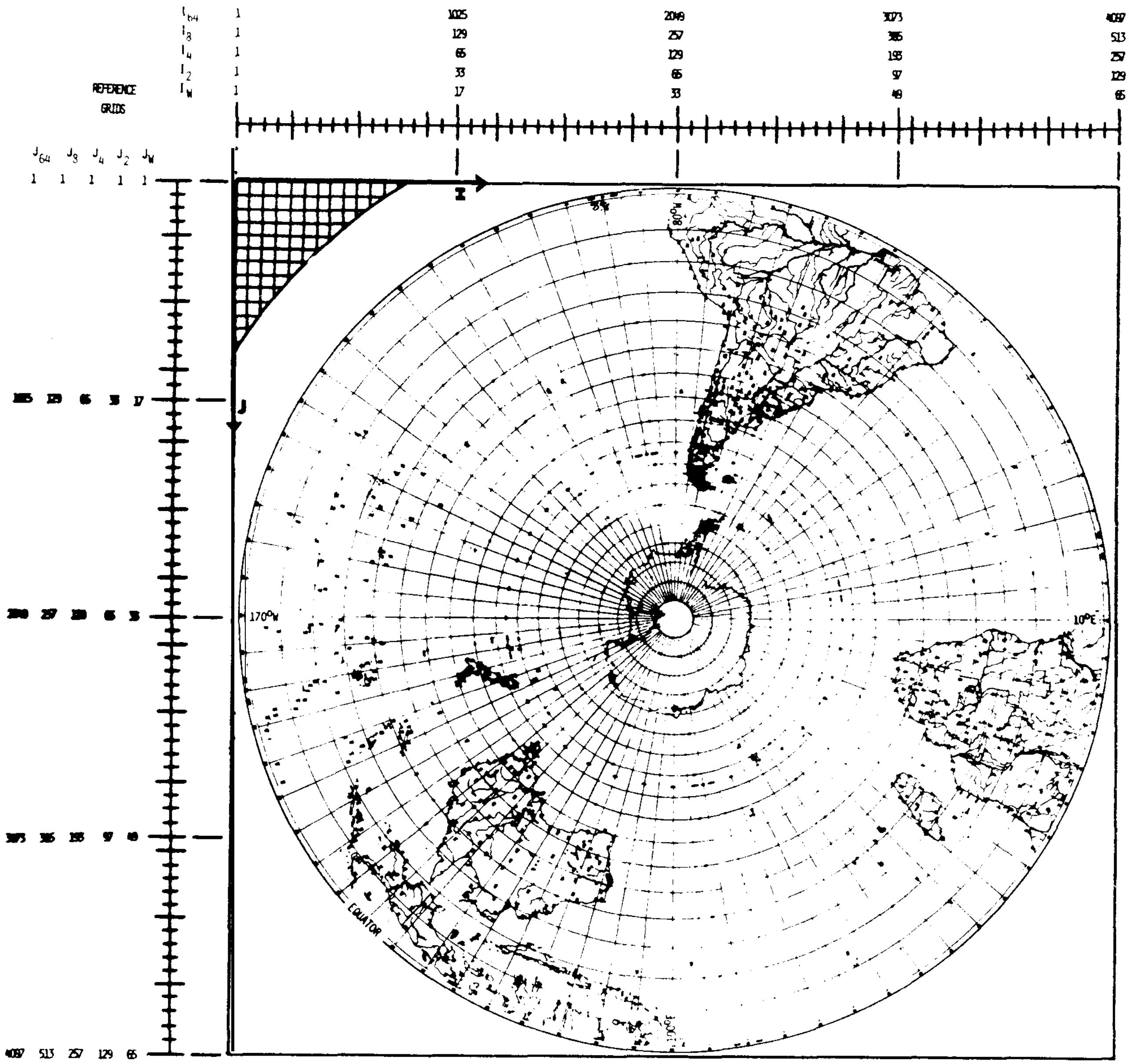


Figure 3.9. The (I,J) indices for the Whole-mesh and Finer-mesh Reference Grids of the Southern Hemisphere. The subscripts denote whole-mesh (I_w,J_w), half-mesh (I_2,J_2), quarter-mesh (I_4,J_4), eighth-mesh (I_8,J_8), and sixty-fourth-mesh (I_{64},J_{64}) indices. The whole-mesh grid spacing is displayed in the upper-left corner.

Table 3.4. Parameters for all the Polar Stereographic Reference Grids.

PARAMETER	DESCRIPTION
H	hemisphere indicator (see eq. 2.3)
$\phi_o = (H)(60^\circ$ latitude)	standard latitude
M	mesh factor (see Tabie 3.3)
d_e (at $\phi = (H)(60^\circ$ latitude))	distance between grid points on the earth's surface at $(H)(60^\circ$ latitude) (see eq. 3.4)
I	grid-point index in the I direction (see Tabie 3.3)
J	grid-point index in the J direction (see Table 3.3)
(I_p,J_p)	grid-point location of the pole (see Table 3.3)

The (I,J) indexing convention and the geographical orientations of the two reference grids also apply to their finer-mesh counterparts. The I index increases from left to right across the grid and the J index increases from the top of the grid to the bottom. If (I_{np},J_{np}) represents the (I,J) indices of the North Pole, column $I = I_{np}$ coincides with the 100°E meridian in the top half of the grid and with the 80°W meridian in the bottom half of the grid; row $J = J_{np}$ coincides with the 170°W meridian in the left half and with the 10°E meridian in the right half. If (I_{sp},J_{sp}) represents the (I,J) indices of the South Pole, column $I = I_{sp}$ coincides with 80°W in the top half of the grid and with 100°E in the bottom half of the grid; row $J = J_{sp}$ coincides with 170°W on the left and with 10°E on the right. Indices (I,J) of one grid may be converted to indices of another grid by eqs. (3.16) and (3.17).

The orientations of the grid-point Cartesian coordinate systems (X,Y) for the Finer-mesh Reference Grids of the Northern and Southern Hemispheres are the same as for the Whole-mesh Reference Grids (see Figs. 3.6 and 3.7). Equations for (X,Y) coordinates in multiples of the appropriate grid length d_i are obtained from eqs. (3.7) and (3.8) with $H = +1$ and -1 for the Northern and Southern Hemispheres, respectively. Gridded wind components are oriented using the same conventions as the Whole-mesh Reference Grids.

Latitude and longitude may be determined from a grid point's (I,J) coordinates from eqs. (3.11) and (3.12) with the mesh factor M specified in Table 3.3. The (I,J) coordinates of any point on the earth's surface can be determined by eqs. (3.13)-(3.15).

In summary, eqs. (3.1)-(3.15) apply to the Finer-mesh Reference Grids, as well as the other polar stereographic grids. Eqs. (3.16) and (3.17) provide a means of relating indices of different grids.

3.1.3 POLAR STEREOGRAPHIC GRIDS FOR NUMERICAL WEATHER ANALYSIS AND FORECASTING

A number of grids for specific applications have been defined for various numerical weather analysis and forecasting models used at AFGWC. These grids are areal subsets of the reference grids and vary from small window (about 3000 km by 3000 km) to hemispheric in areal coverage. A brief overview of each applications grid will be presented in this section. Descriptions of the functions of the models are presented by Tarbell and Hoke (1979).

Eqs. (3.1)-(3.17) apply to these polar stereographic grids with the basic grid parameters summarized in Table 3.5.

3.1.3.1. NORTHERN AND SOUTHERN HEMISPHERIC OCTAGONS

Both whole-mesh and half-mesh versions of Northern and Southern Hemispheric octagonal grids are used operationally at AFGWC. These grids were developed to meet the demands for higher-accuracy forecasts while satisfying computer constraints.

3.1.3.1.1. WHOLE-MESH OCTAGONS

The <u>Whole-mesh</u> Octagon was the first grid used for numerical weather prediction at AFGWC. Octagon grids have been defined for both the Northern and Southern Hemispheres (Figs. 3.10 and 3.11). The grid size is <u>47x51</u> with the corner portions of the rectangle deleted. That is, for the first row (J = 1) of the Octagon, only the grid points (15,1) through (33,1) are included; in row two, points (14,2) through (34,2) are used. Similarly, each successive row includes two more grid points until a full complement of 47 grid points is attained in row 15. After row 37, in which points (1,37) through (47,37) are included, each successive row deletes two points (one at each end). Row 38 includes (2,38) through (46,38), row 39 includes (3,39) through (45,39), and so on. The final row of the Octagon includes points (15,51) through (33,51).

Information is actually stored for the octagon on a rectangular grid. The information in the corners of this grid, outside the octagon, is often meaningless and may simply be assigned a constant value or may be extraneous values left over from prior computations. For example, for the Northern Hemispheric whole-mesh analysis data base that is designated at AFGWC as literal RTGWCA, data in the corners of the grid should usually be ignored.

The earth's pole is represented by grid point (24,26) for both the Northern and Southern Hemispheric Whole-mesh Octagons, whereas on the Whole-mesh Reference Grid the pole location is (33,33). Whole-mesh Octagon indices may be converted to their Whole-mesh Reference-grid values by eqs. (3.16) and (3.17), where (I,J) are the indices on the Whole-mesh Octagon, (I',J') the indices on the Whole-mesh Reference Grid, and M = M' = 1 being the respective mesh factors.

Various parameters of the Whole-mesh Octagons are summarized in Table 3.5.

3.1.3.1.2. HALF-MESH OCTAGONS

The Half-mesh Octagons (Figs. 3.10 and 3.11), which contain 93x101 points, are subsets of the Half-mesh Reference Grids. As with the Whole-mesh Octagons, grid points in the corner portions of the rectangle are not used. Half-mesh Octagon indices (I,J) may be converted to their Half-mesh Reference-grid values (I',J') using eqs. (3.16) and (3.17), where $(I_p,J_p) = (47,51)$, $(I_p',J_p') = (65,65)$, and $M = M' = 1/2$. Whole-mesh Octagon indices (I,J) may be converted to their Half-mesh Octagon values (I',J') also using eqs. (3.16) and (3.17) with $(I_p,J_p) = (24,26)$, $(I_p',J_p') = (47,51)$, $M = 1$, and $M' = 1/2$.

Various parameters of the Half-mesh Octagons are listed in Table 3.5.

3.1.3.1.3 HISTORICAL NOTE

Size, shape, and other attributes of the Octagons were not arbitrarily specified. Development of the grid system began in the mid-1950s at the Joint Numerical Weather Prediction Unit (JNWPU), Suitland, Maryland (H. A. Bedient, personal communication). Many of these attributes resulted from constraints imposed by computer systems in those early days of operational numerical weather prediction. The line printer played an important role, for example. Because this device printed characters at a density of 10 characters per inch horizontally and vertically on the page, computer-generated gridded output was conveniently plotted using a grid spacing of 1/2 inch for the Whole-mesh Octagon. On a polar stereographic projection with map scale μ of 1:30,000,000

Table 3.5. Hemispheric Grids for Numerical Weather Analysis and Forecasting. The pole location is with respect to each particular grid, not the Reference Grids. NH indicates Northern Hemisphere ($H = +1$, $\phi_o = 60°N$) and SH indicates Southern Hemisphere ($H = -1$, $\phi_o = 60°S$).

GRID	DOMAIN	MESH FACTOR (M)	ARRAY SIZE IxJ = TOTAL NUMBER OF POINTS	GRID POINT LOCATION OF THE POLE (I_p,J_p)
Whole-mesh Octagon	NH/SH	1	47x51 = 2,397	(24,26)
Half-mesh Octagon	NH/SH	1/2	93x101 = 9,393	(47,51)
TRONEW	NH/SH	1/2	128x128 = 16,384	(65,65)
AWSPE	NH only	1	53x57 = 3,021	(27,29)
SIXLVL	NH/SH	1	51x51 = 2,601	(26,26)
3DNEPH	NH/SH	1/8	512x512 = 262,144	(257,257)
SGDB	NH/SH	1/64	4096x4096 = 16,777,216	(2049,2049)

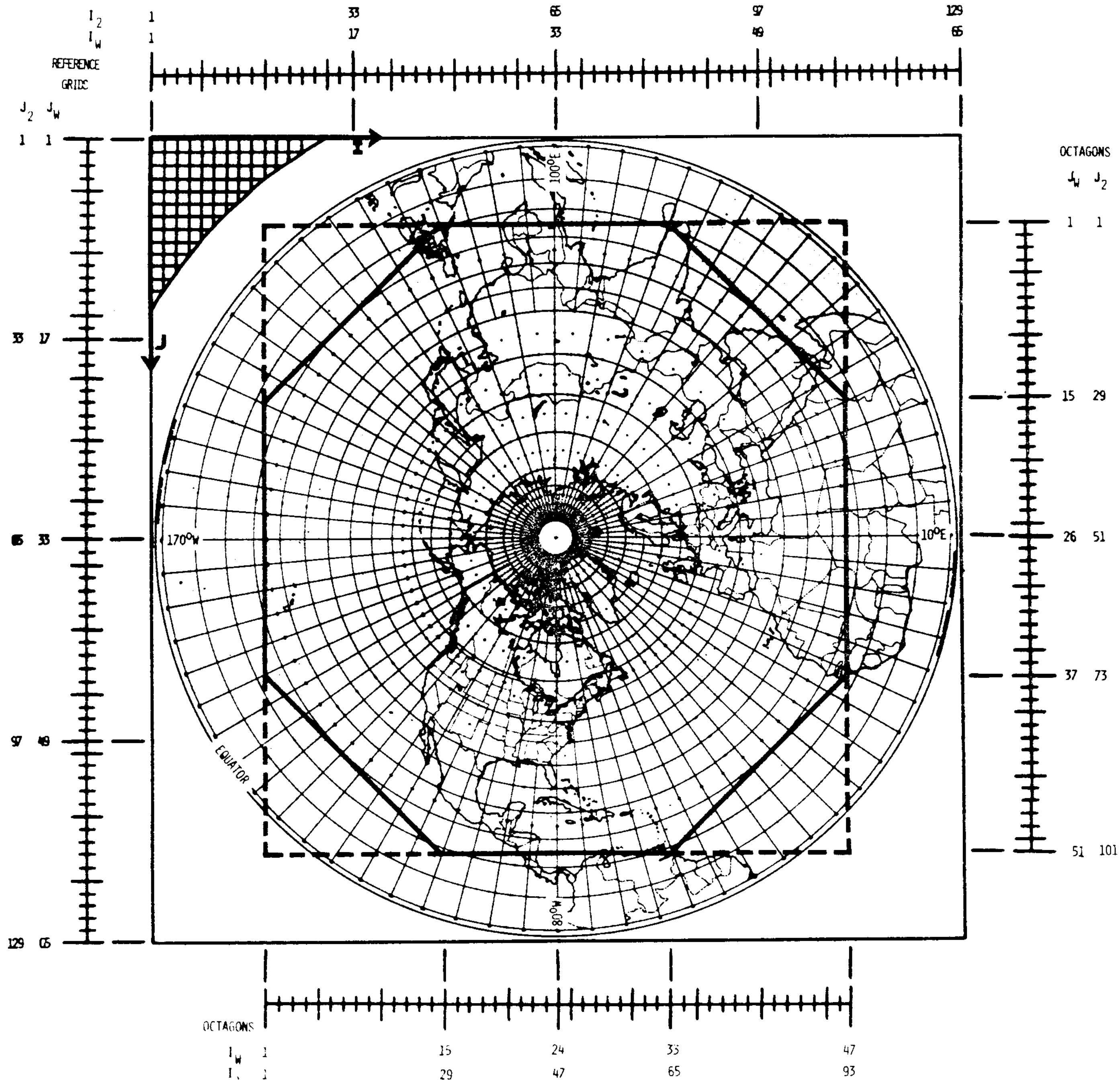


Figure 3.10. The Whole-mesh and Half-mesh Octagons for the Northern Hemisphere. The domain of the Reference Grids (solid outer border) is also plotted. The indices (I_W, J_W) and (I_2, J_2) designate the coordinates for the whole-mesh and half-mesh versions, respectively, with respect to the Octagons and the Reference Grids. The dashed lines indicate that data on the Octagons are actually stored in a rectangular data base. The whole-mesh grid spacing is displayed in the upper-left corner.

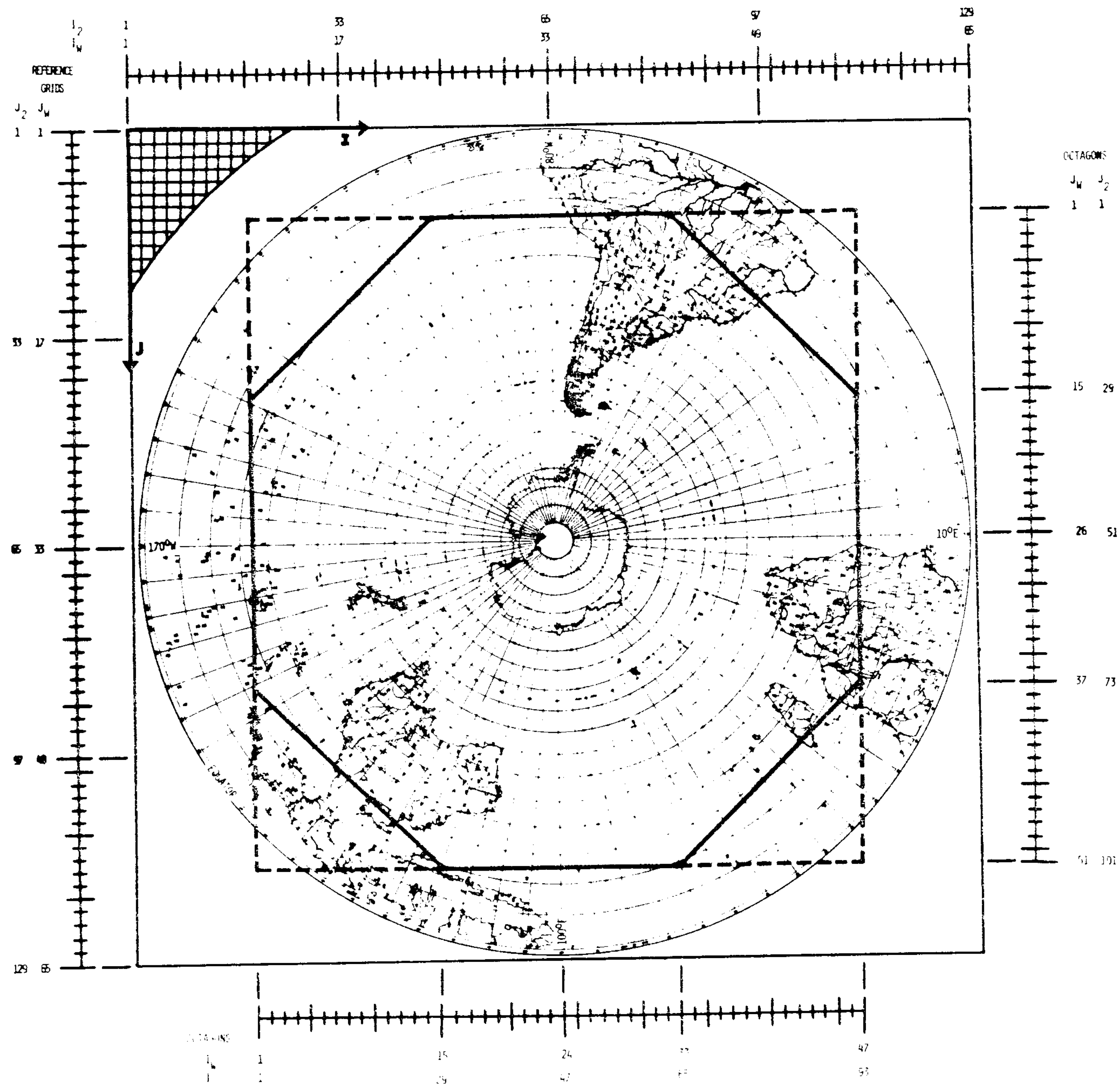


Figure 3.11. The Whole-mesh and Half-mesh Octagons for the Southern Hemisphere. The domain of the Reference Grids (solid outer border) is also plotted. The indices (I_W, J_W) and (I_2, J_2) designate the coordinates for the whole-mesh and half-mesh versions, respectively, with respect to the Octagons and the Reference Grids. The dashed lines indicate that data on the Octagons are actually stored in a rectangular data base. The whole-mesh grid spacing is displayed in the upper-left corner.

and true at 60°N, which was a common projection then and now, 1/2 inch corresponds to exactly 381 km on the earth at 60°N.

Because of the severe computer memory constraints of the IBM 704 computer system used at that time, the number of grid points had to be less than 2048. The 1977 grid points of the Whole-mesh Octagon fit this requirement. The octagon was selected instead of a more circular polygon to simplify development of the numerical models. The 47x51 octagon was selected instead of an equilateral octagon in part, once again, because of the line printer; the 47 grid points in the I direction (left to right) fit on two computer pages side by side. (At that time, only 120 characters could be printed per line on a page.) Although up to 48 grid points would fit on two pages, this larger size was not used because of the desire to have the North Pole located at a grid point, thereby necessitating a grid with odd dimensions. The maximum odd number of grid points that can be included in the J direction (top to bottom) without exceeding the 2048 limit for total points is 51.

The standard longitude λ_0 was selected as 10°E to maximize the number of important data points near the boundaries that could be included within the domain of the Northern Hemispheric Whole-mesh Octagon. For example, a rotation of the Octagon by less than 15° longitude to the west places Dakar outside the domain, while a rotation of about 25° longitude to the west eliminates Manila.

The Southern Hemispheric Whole-mesh Octagon was then set up to be analogous to its Northern Hemispheric counterpart, and the Half-mesh Octagons were devised to meet the demands for higher resolution.

3.1.3.2. AWSPE AND SIXLVL HEMISPHERIC GRIDS

The grid for storing information pertinent to the Air Weather Service Primitive Equation Model (AWSPE) is a <u>53x57</u> subset of the Whole-mesh Reference Grid. This subset grid is currently defined and used operationally for the Northern Hemisphere only (Fig. 3.12). Although the (I,J) indexing convention of the grid for <u>storing</u> AWSPE output is as shown in Fig. 3.12, in the actual indexing convention <u>internal</u> to the AWSPE computer program the lower-left corner is grid point (1,1).

The grid for the Six-level Baroclinic Prediction Model (SIXLVL) is a <u>51x51</u> subset of the Whole-mesh Reference Grid. SIXLVL grids for both the Northern and Southern Hemisphere (Figs. 3.13 and 3.14) are used operationally.

All conventions and equations described in the section on reference grids apply for the AWSPE and SIXLVL grids. Indices of grid points for these grids may be converted to their Whole-mesh Reference-grid values using information from Tables 3.3 and 3.5 and eqs. (3.16) and (3.17).

3.1.3.3. 3DNEPH GRIDS

The grids for the Three-dimensional Nephanalysis Model (3DNEPH) are 512x512 subsets of the 513x513 Eighth-mesh Reference Grids. The bottom row (J = 513) and the right-most column (I = 513) are not included in the hemispheric subset grids used by the 3DNEPH (Figs. 3.15 and 3.16).

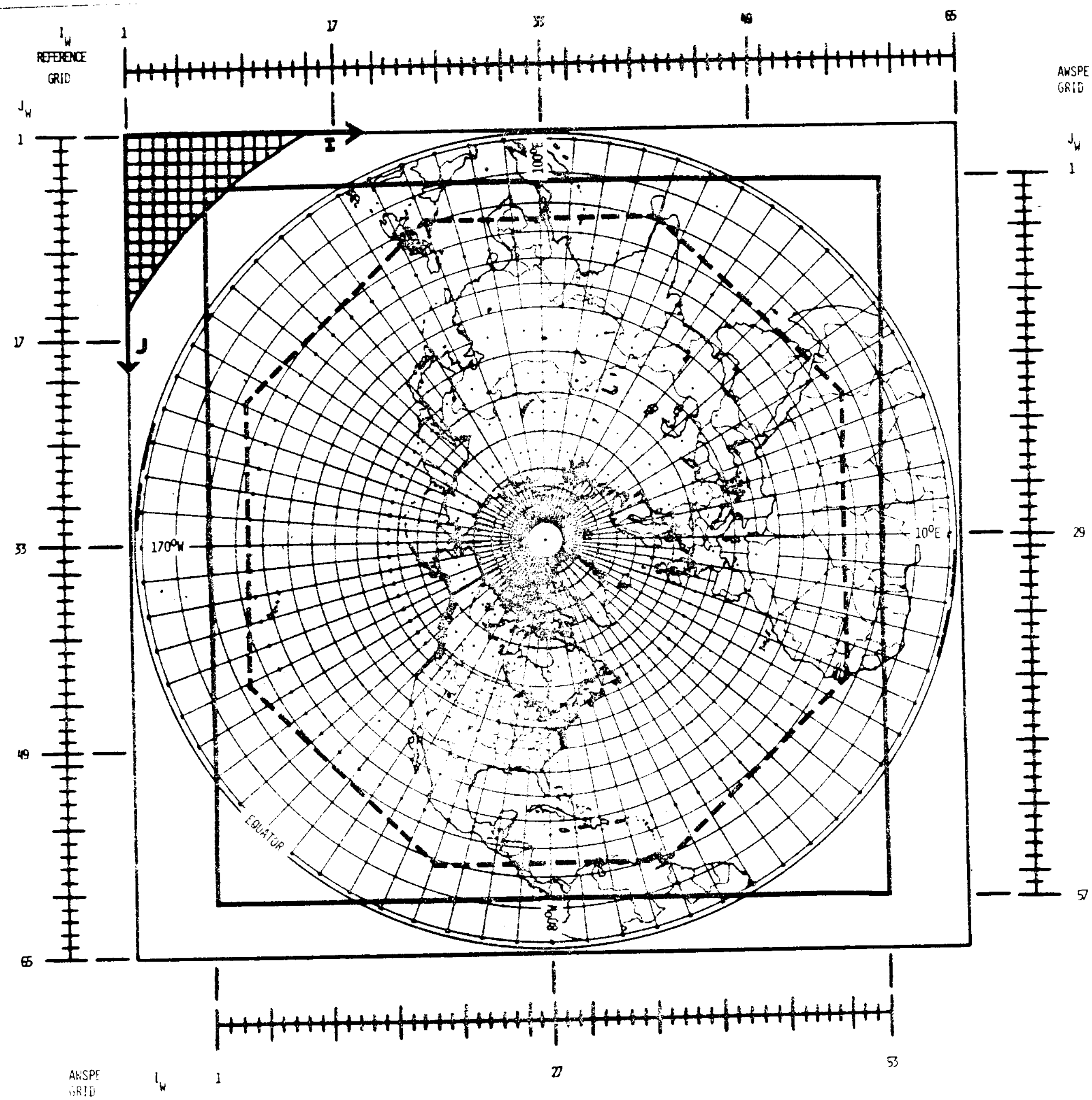


Figure 3.12. The grid (inner solid lines) for the Air Weather Service Primitive-equation Model (AWSPE). The domains of the Northern Hemispheric Reference Grids (solid outer border) and the Octagon grids (dashed lines) are also indicated. The indices (I_W,J_W) designate the coordinates for both the Whole-mesh Reference Grid and the AWSPE grid. The whole-mesh grid spacing is displayed in the upper-left corner.

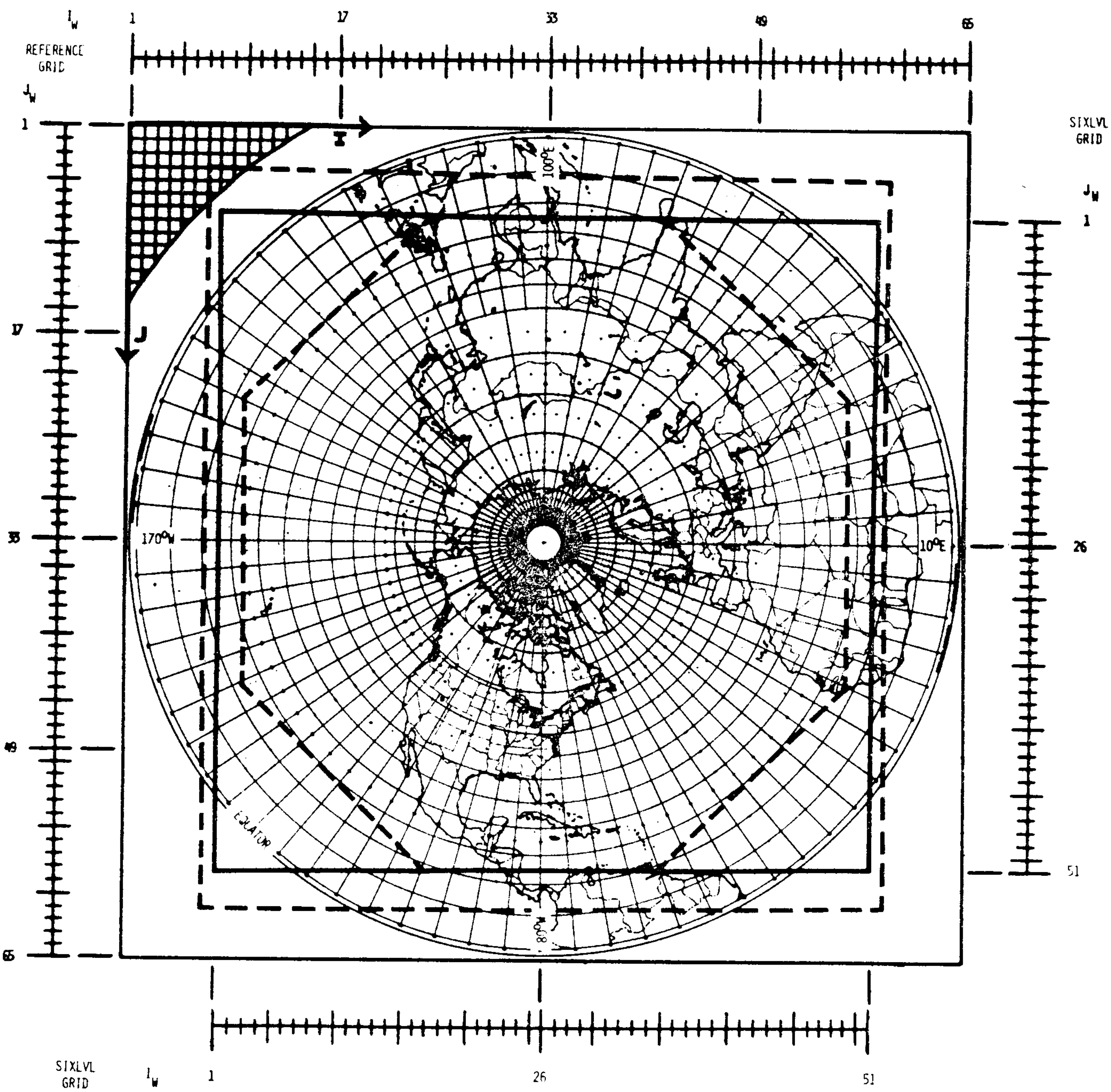


Figure 3.13. The grid (inner solid lines) for the Six-level Baroclinic Prediction Model (SIXLVL) for the Northern Hemisphere. The domains of the Northern Hemispheric Reference Grids (solid outer border), the AWSPE grid (outer dashed lines), and the Octagon grids (inner dashed lines) are also indicated. The indices (I_W,J_W) designate the coordinates for both the Whole-mesh Reference Grid and the SIXLVL grid. The whole-mesh grid spacing is displayed in the upper-left corner.

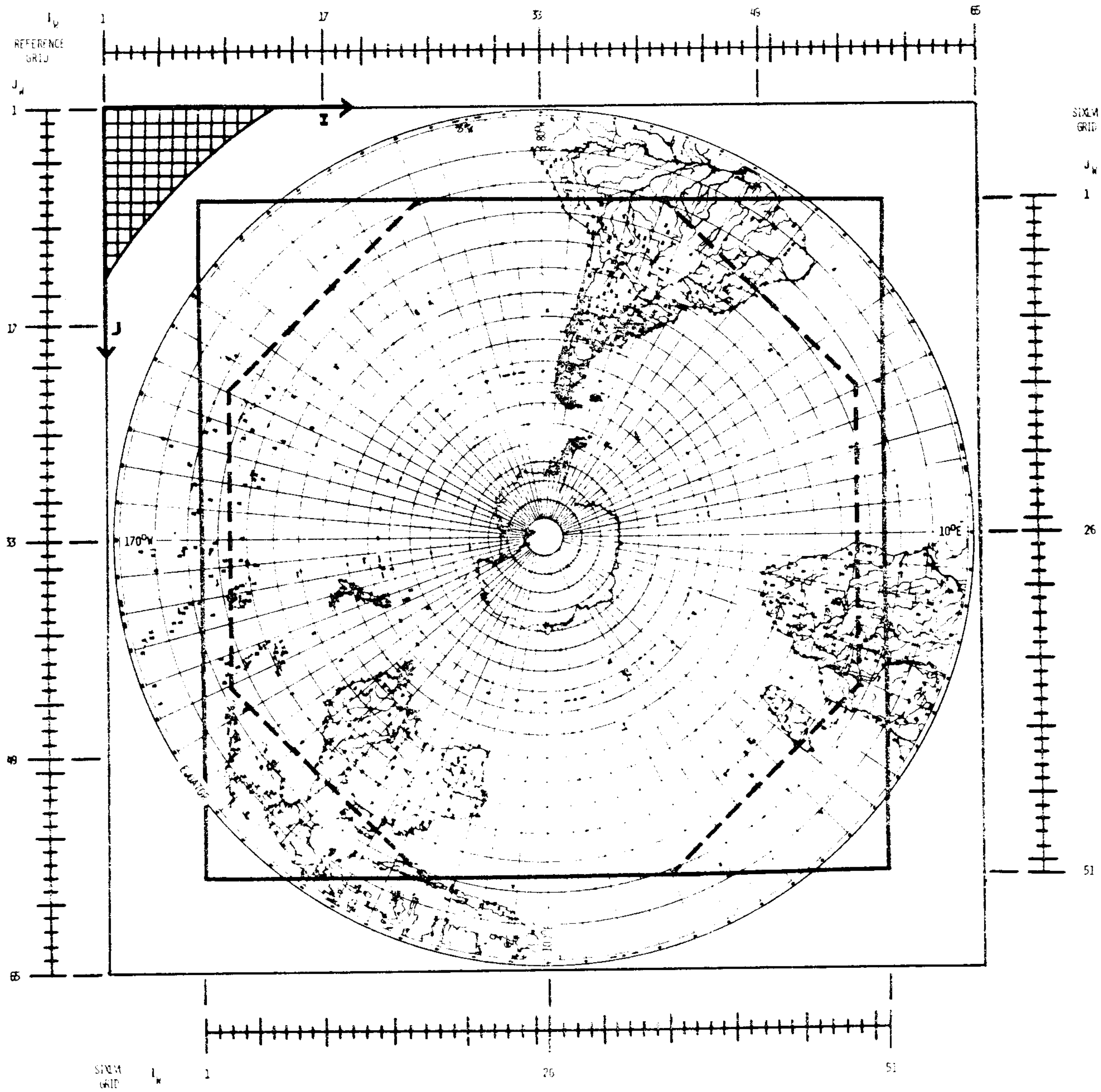


Figure 3.14. The grid (inner solid lines) for the Six-level Baroclinic Prediction Model (SIXLVL) for the Southern Hemisphere. The domains of the Southern Hemispheric Reference Grids (solid outer border) and the Octagon grids (dashed lines) are also indicated. The indices (I_W,J_W) designate the coordinates for both the Whole-mesh Reference Grid and the SIXLVL grid. The whole-mesh grid spacing is displayed in the upper-left corner.

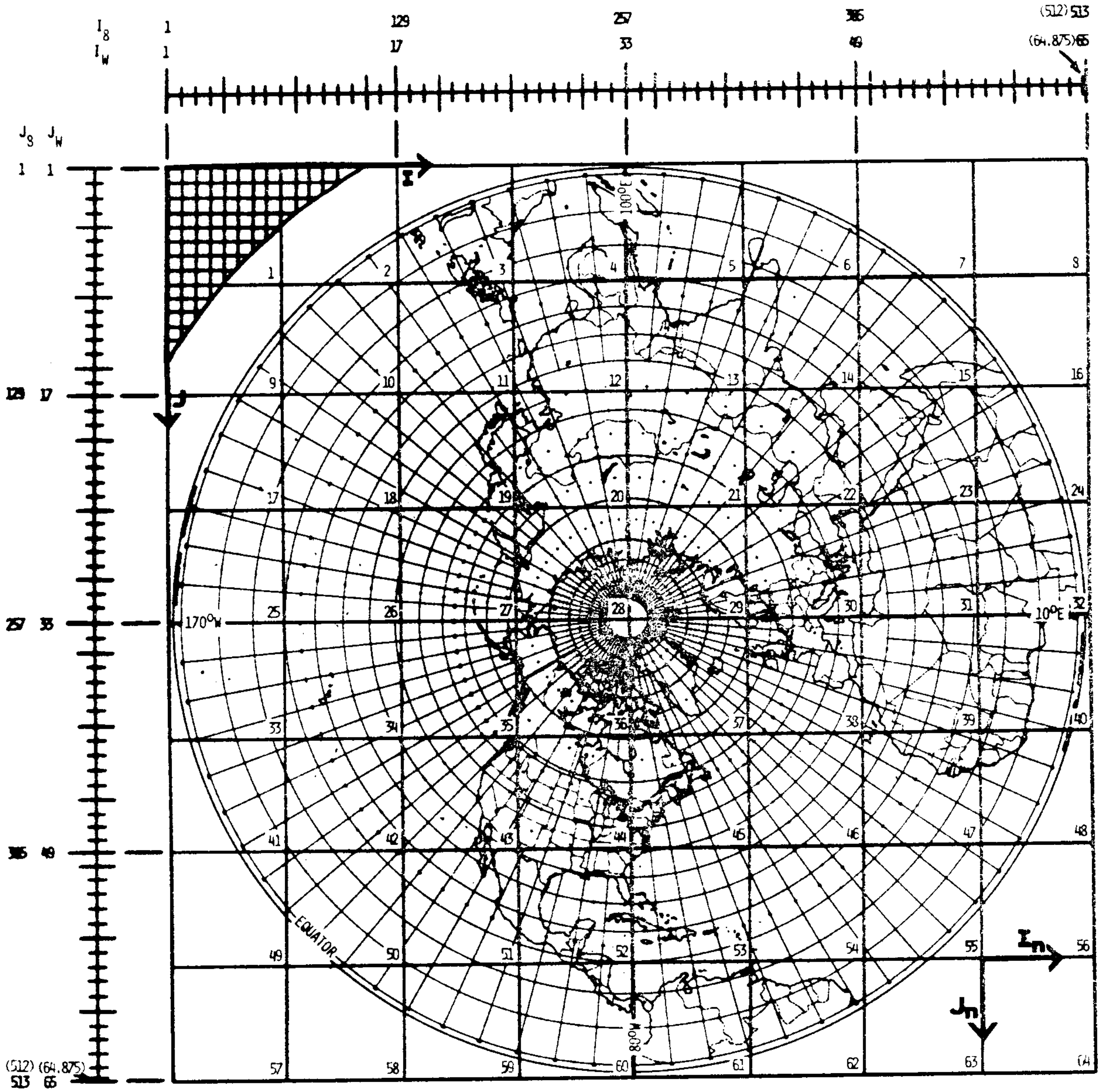


Figure 3.15. The grid system of the Three-dimensional Nephanalysis (3DNEPH) for the Northern Hemisphere. The (I,J) indexing convention is the same as that of the Eighth-mesh Reference Grid. The indices (I_w,J_w) and (I_8,J_8) denote the whole-mesh and eighth-mesh coordinates, respectively, for the Reference Grids and the 3DNEPH. The 64 3DNEPH boxes are indicated; the four corner boxes are not used. The (I_n,J_n) coordinate axes in the lower-right corner show the 3DNEPH Box IJ convention for a sample 3DNEPH box. Each 3DNEPH box contains the grid points on the upper and left boundaries of the box, but not the lower and right boundaries. The labels (64.875) and (512) on the axes respectively indicate the whole-mesh and eighth-mesh values of the last row of the 3DNEPH grid system, which has one less row than the Eighth-mesh Reference Grid. The whole-mesh grid spacing is displayed in the upper-left corner.

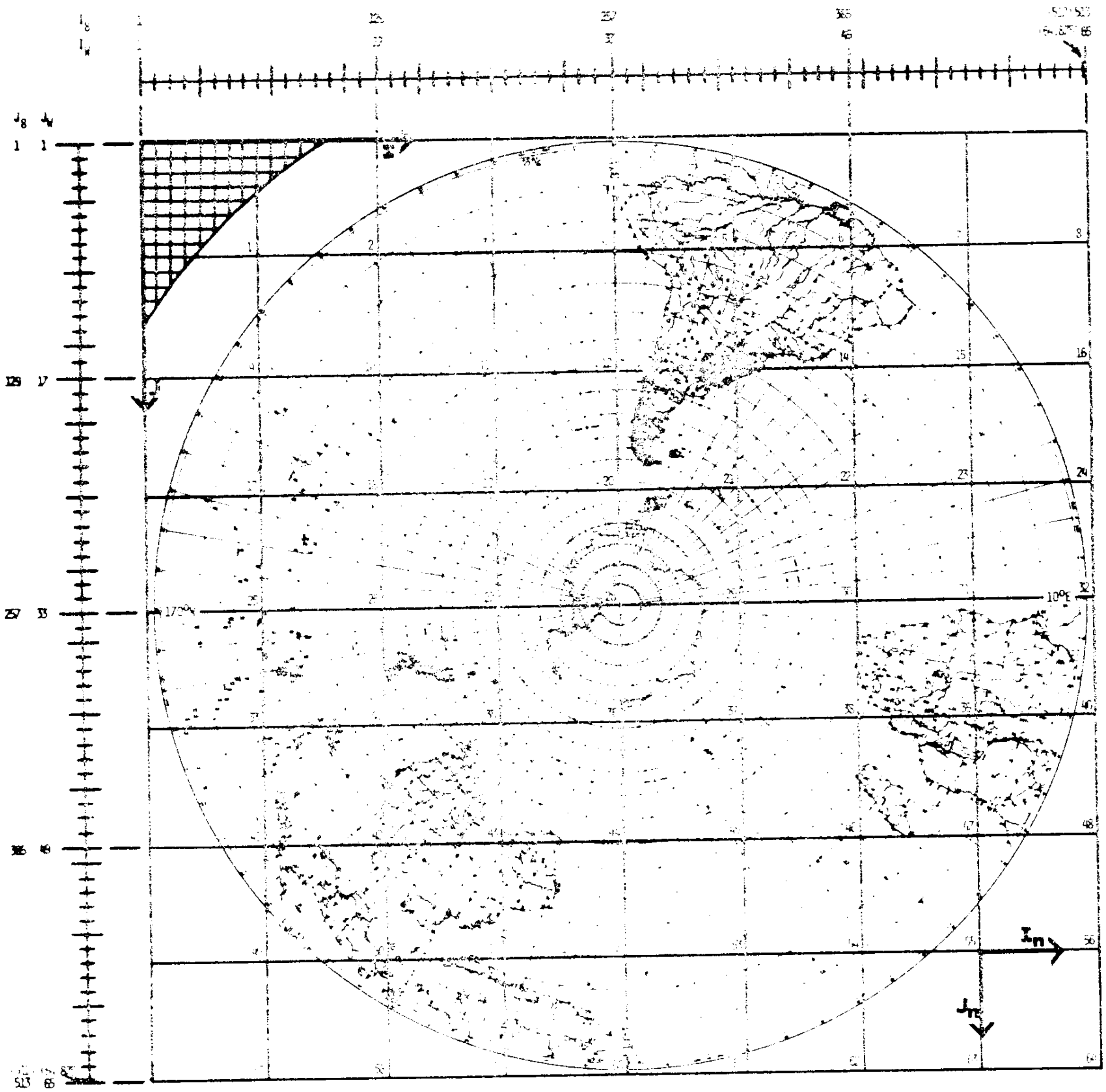


Figure 3.16. The grid system of the Three-dimensional Nephanalysis (3DNEPH) for the Southern Hemisphere. The (I,J) indexing convention is the same as that of the Eighth-mesh Reference Grid. The indices (I_w,J_w) and (I_8,J_8) denote the whole-mesh and eighth-mesh coordinates, respectively, for the Reference Grids and the 3DNEPH. The 64 3DNEPH boxes are indicated; the four corner boxes are not used. The (I_n,J_n) coordinate axes in the lower-right corner show the 3DNEPH Box IJ convention for a sample 3DNEPH box. Each 3DNEPH box contains the grid points on the upper and left boundaries of the box, but <u>not</u> the lower and right boundaries. The labels (64.875) and (512) on the axes respectively indicate the whole-mesh and eighth-mesh values of the last row of the 3DNEPH grid system, which has one less row than the Eighth-mesh Reference Grid. The <u>whole-mesh</u> grid spacing is displayed in the upper-left corner.

Information stored on 3DNEPH grids is assumed to be representative of conditions surrounding each grid point. This is in contrast to the convention for the Satellite Global Data Base (see Section 3.1.3.5).

As noted by Fye (1978), the array size (262,144 points) of the 3DNEPH hemispheric grid "requires partitioning to facilitate automated processing." For each hemisphere, the 512x512 array is therefore divided into 64 areas called <u>3DNEPH boxes</u> (Figs. 3.15 and 3.16), denoted here by B_n. The four corner boxes, which lie off the hemisphere, are not used. The box number B_n can be calculated from indices (I_8,J_8) of the Eighth-mesh Reference Grid according to

$$B_n = 1 + \mathrm{INT}(I_8-1,\ 64) + 8\,[\mathrm{INT}(J_8-1,\ 64)] \tag{3.18}$$

for $1 \leq I_8 \leq 512$ and $1 \leq J_8 \leq 512$. INT designates a function that provides the <u>integer</u> portion of the division of the first argument by the second. Also, we let MOD designate a mathematical function in which the functional value is the <u>remainder</u> of the division of the first argument by the second argument. For example, MOD(7,2) = 1 and INT(7,2) = 3; MOD(57,8) = 1 and INT(57,8) = 7. Note that $1 \leq B_n \leq 64$.

Within each box an indexing convention (I_n,J_n), called the <u>3DNEPH Box IJ convention</u>, is used to designate the 64x64 array of grid points (see Fig. 3.17). Box IJ indices (I_n,J_n) are related to their corresponding Eighth-mesh Reference-grid indices (I_8,J_8) by

$$I_8 = I_n + 64[\mathrm{MOD}(B_n-1,\ 8)] \quad , \tag{3.19}$$

$$J_8 = J_n + 64[\mathrm{INT}(B_n-1,\ 8)] \quad , \tag{3.20}$$

where B_n is the 3DNEPH box number, $1 \leq I_n \leq 64$, and $1 \leq J_n \leq 64$. Eighth-mesh Reference Grid indices may be transformed to 3DNEPH Box IJ indices for box B_n by

$$I_n = 1 + \mathrm{MOD}(I_8-1,\ 64) \quad , \tag{3.21}$$

$$J_n = 1 + \mathrm{MOD}(J_8-1,\ 64) \quad . \tag{3.22}$$

3.1.3.4. TRONEW HEMISPHERIC GRIDS

The grids for the Tropical Cloud Forecast Model (TRONEW) are the same as the 129x129 Half-mesh Reference Grids (Figs. 3.18 and 3.19). Although the TRONEW grids are 129x129, useful information is only stored on the 128x128 subsets. The bottom row (J = 129) and the right-most column (I = 129) of the Half-mesh Reference Grids are not included in the Northern and Southern Hemispheric grids used by TRONEW. All conventions and equations described in the sections on the generalized equations (Section 3.1.1) and the finer-mesh polar stereographic reference grids (Section 3.1.2.3) apply for the TRONEW grids. Various parameters of these grids are listed in Table 3.5.

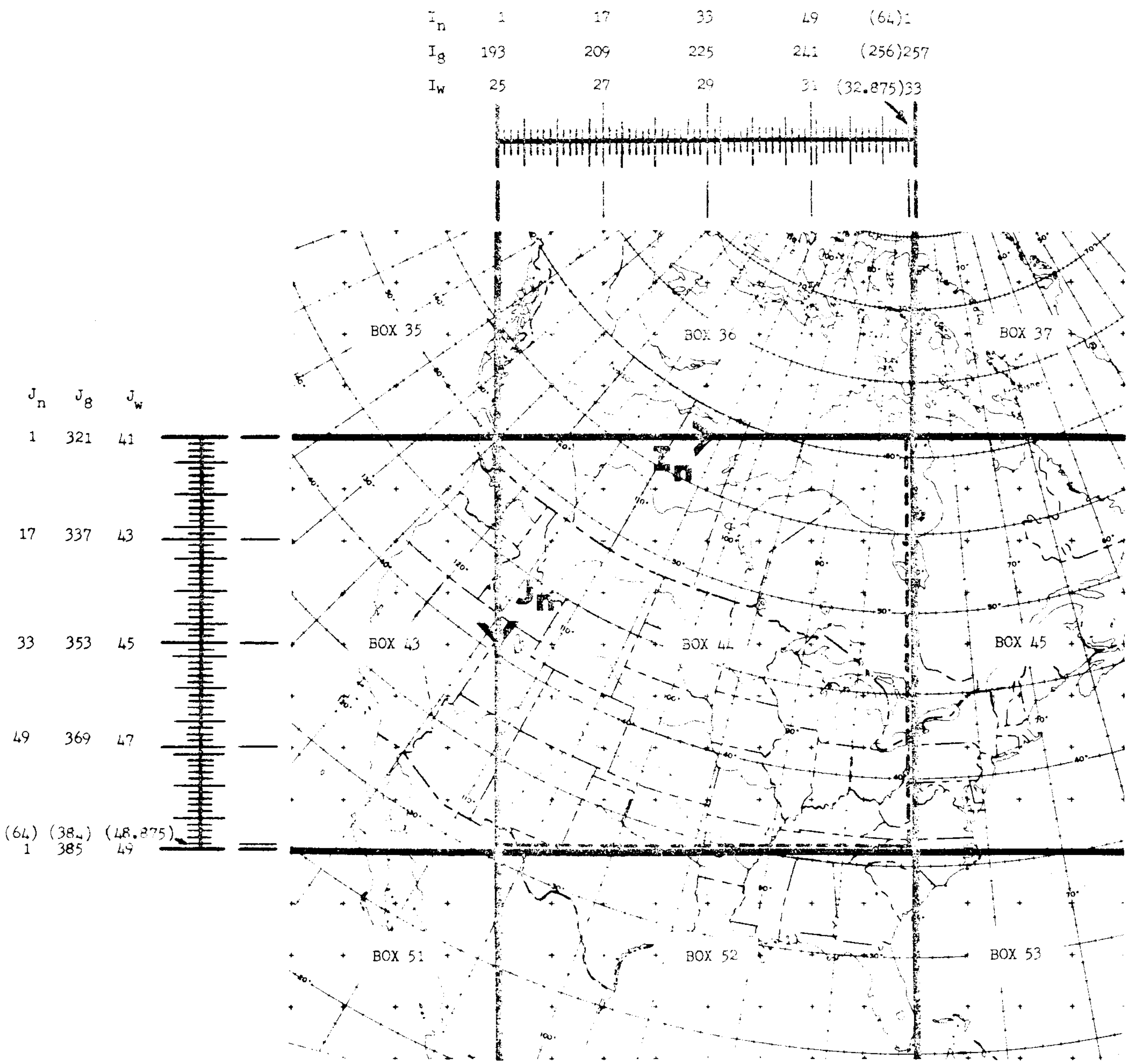


Figure 3.17. The relationship of 3DNEPH Box IJ indices (I_n, J_n) to Whole-mesh Reference Grid indices (I_w, J_w) and Eighth-mesh Reference Grid indices (I_8, J_8) for an example 3DNEPH box (box number $B_n = 44$). Note that grid points on the lower and right boundaries (solid lines) of the box are located in adjacent boxes. The dashed lines indicate the actual lower and right boundary rows of the box, with (I,J) indices given in parentheses on the axes.

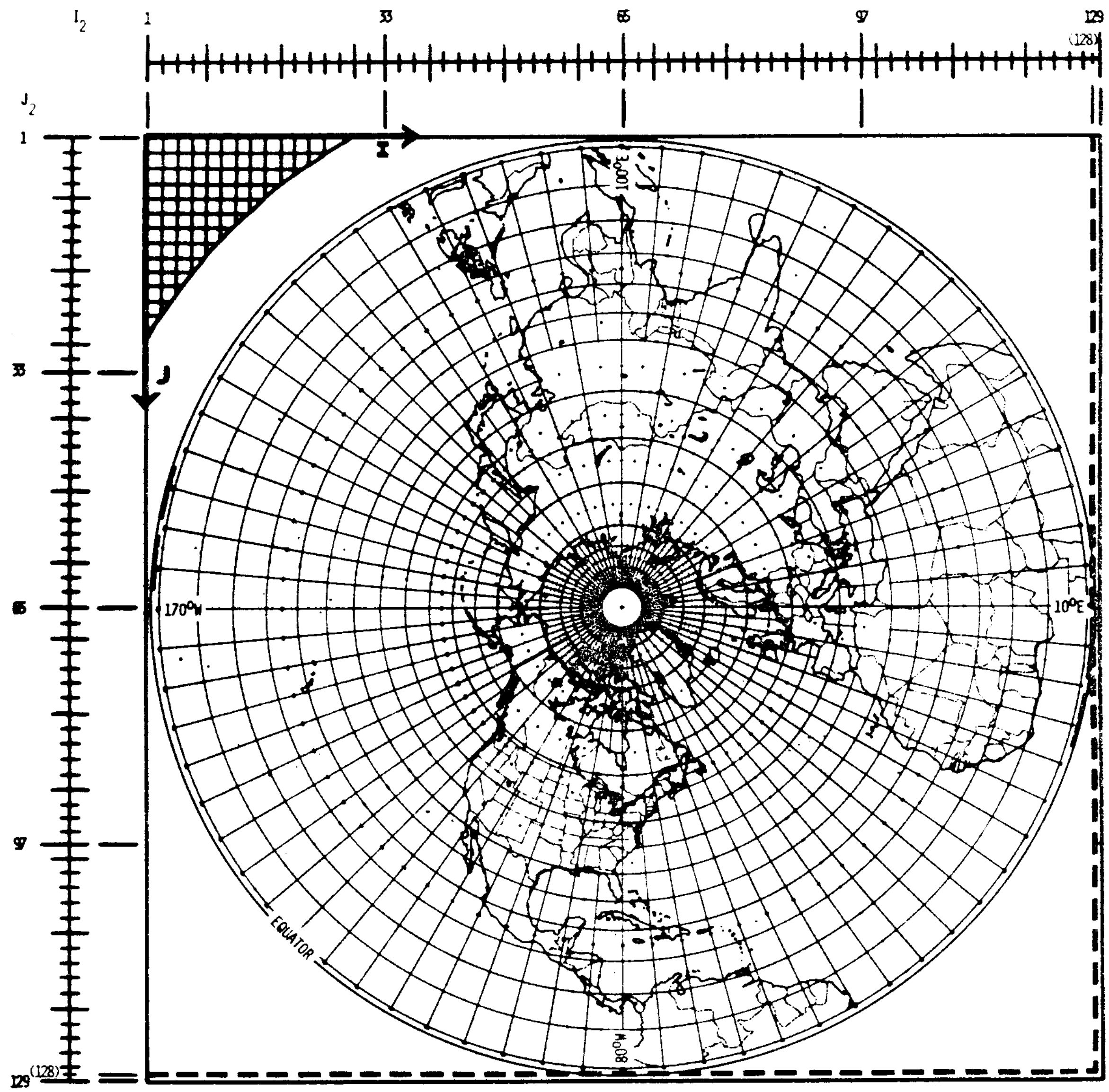


Figure 3.18. The Northern Hemispheric grid of the Tropical Cloud Forecast Model (TRONEW). The grid is half mesh. The (I,J) indexing convention, designated (I_2,J_2), is the same as that of the Half-mesh Reference Grid (solid outer border). The dashed lines, labeled (128) on the axes, indicate that meaningful data are stored on a 128x128 domain, although the size of the data base is 129x129. The whole-mesh grid spacing is displayed in the upper-left corner.

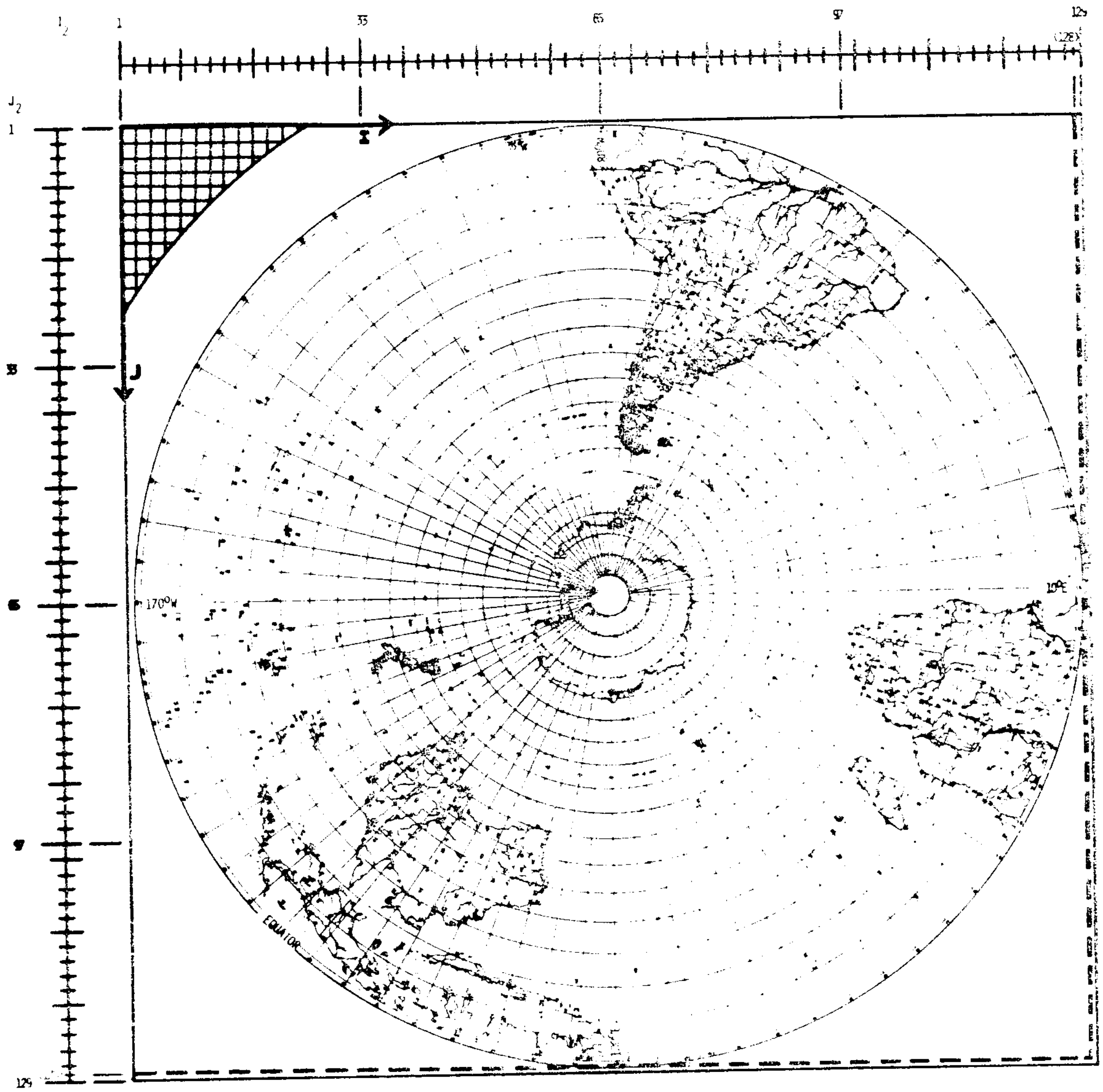


Figure 3.19. The Southern Hemispheric grid of the Tropical Cloud Forecast Model (TRONEW). The grid is half mesh. The (I,J) indexing convention, designated (I_2,J_2), is the same as that of the Half-mesh Reference Grid (solid outer border). The dashed lines, labeled (128) on the axes, indicate that meaningful data are stored on a 128x128 domain, although the size of the data base is 129x129. The whole-mesh grid spacing is displayed in the upper-left corner.

3.1.3.5 SATELLITE GLOBAL DATA BASE GRIDS

The Satellite Global Data Base (SGDB) uses a 4096x4096 subset of the Sixty-fourth-mesh Reference Grid. The bottom row (J = 4097) and the right-most column (I = 4097) of this reference grid are not included in the two hemispheric subsets of the SGDB (Figs. 3.20 and 3.21).

Like the 3DNEPH grids, the SGDB hemispheric grids are partitioned into boxes to facilitate computer processing of satellite data. For each hemisphere, there are 4096 SGDB boxes (Figs. 3.20 and 3.21), each consisting of a 64x64 array of points, for a total of 16,777,216 grid points per hemisphere. Each SGDB box contains one Whole-mesh Reference Grid Point (I_w, J_w), which coincides with the sixty-fourth-mesh point in the upper-left corner of the SGDB box (Fig. 3.22). Imagery is not stored in those boxes that lie off the hemisphere. SGDB boxes are numbered according to

$$B_s = (I_w - 1) + 64(J_w - 1) \quad , \quad \begin{cases} 1 \leq I_w \leq 64 & , \\ 1 \leq J_w \leq 64 & , \end{cases} \tag{3.23}$$

where (I_w, J_w) are the indices of the Whole-mesh Reference Grid Point at the SGDB point in the upper-left corner of the box and B_s is the SGDB box number. The box number can be alternately calculated from the Sixty-fourth-mesh Reference Grid Indices (I_{64}, J_{64}) according to

$$B_s = \mathrm{INT}(I_{64} - 1,\ 64) + 64\ [\mathrm{INT}(J_{64} - 1,\ 64)] \tag{3.24}$$

for $1 \leq I_{64} \leq 4096$ and $1 \leq J_{64} \leq 4096$. Note that $0 \leq B_s \leq 4095$.

Within each box an indexing convention, called the SGDB Box IJ convention, is used. SGDB Box IJ indices (I_s, J_s) are related to their Sixty-fourth-mesh Reference Grid indices (I_{64}, J_{64}) by

$$I_{64} = I_s + 64[\mathrm{MOD}(B_s,\ 64)] \quad , \tag{3.25}$$

$$J_{64} = J_s + 64[\mathrm{INT}(B_s,\ 64)] \quad , \tag{3.26}$$

where $1 \leq I_s \leq 64$, $1 \leq J_s \leq 64$, and MOD and INT are defined in Section 3.1.3.3. Sixty-fourth-mesh Reference Grid indices may be transformed to SGDB Box IJ indices for box B_s by

$$I_s = 1 + \mathrm{MOD}(I_{64} - 1,\ 64) \quad , \tag{3.27}$$

$$J_s = 1 + \mathrm{MOD}(J_{64} - 1,\ 64) \quad . \tag{3.28}$$

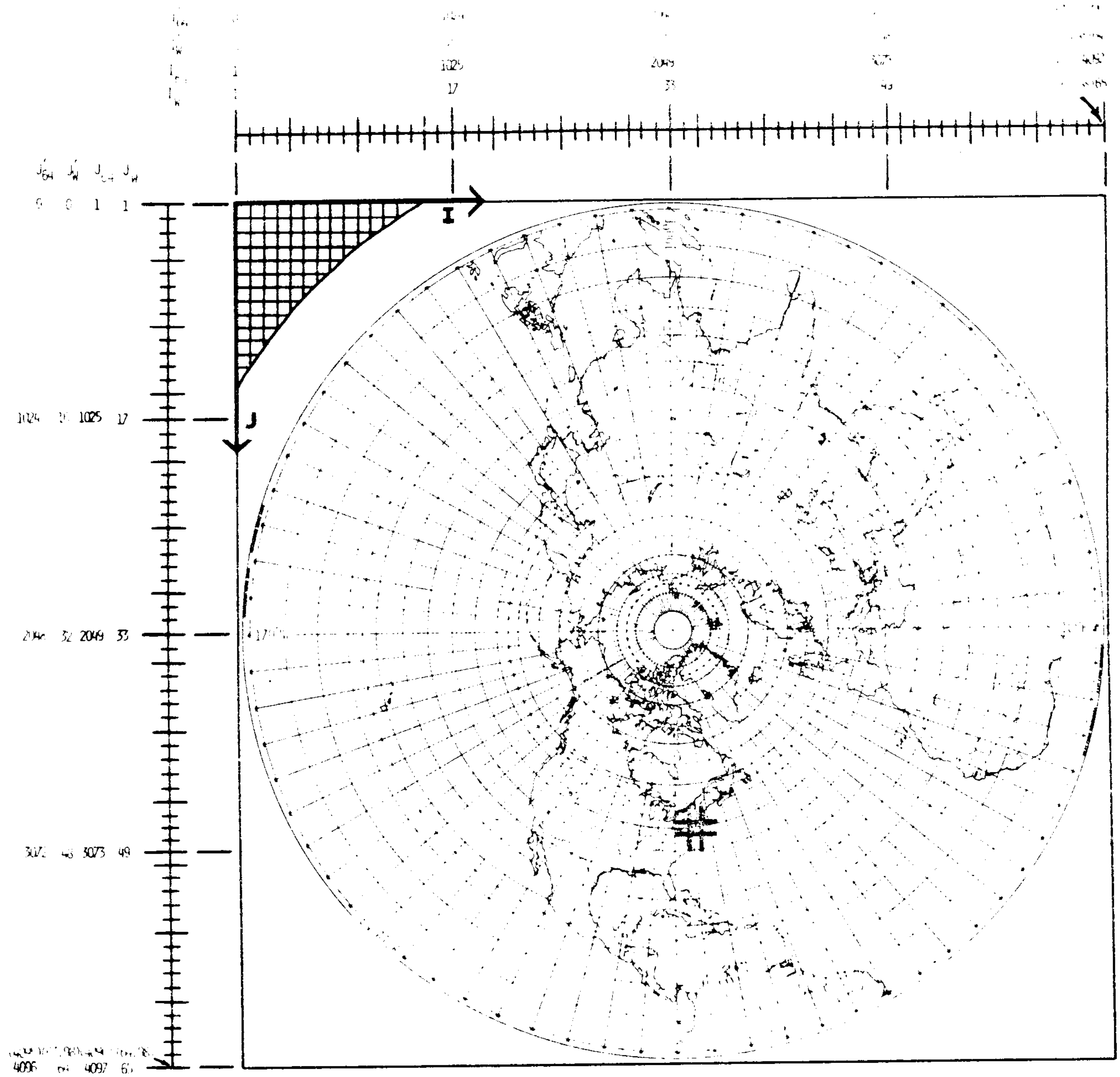


Figure 3.20. The grid system for the Satellite Global Data Base (SGDB) for the Northern Hemisphere. The (I,J) indexing convention is the same as that of the Sixty-fourth-mesh Reference Grid. The indices (I_w, J_w) and (I_{64}, J_{64}) denote the coordinates of the Whole-mesh Reference Grid and the Sixty-fourth-mesh Reference Grid, respectively, whereas the indices (I_w', J_w') and (I_{64}', J_{64}') denote the numbering convention used in the satellite data processing software (SYNAPS). Examples of the 4096 SGDB boxes, which are one whole-mesh grid length on a side, are given in the upper-left corner of the domain. Imagery is not stored in those boxes that lie off the hemisphere. Each SGDB box contains the rows of grid points on the upper and left boundaries of the box, but not the lower and right boundaries. The index values in parentheses on the axes indicate the values of the last row of the SGDB grid system, which has one less row than the Sixty-fourth-mesh Reference Grid. Over the U.S., box number 2977 (B_s = 2977) is given as an example and is described in more detail in Fig. 3.22.

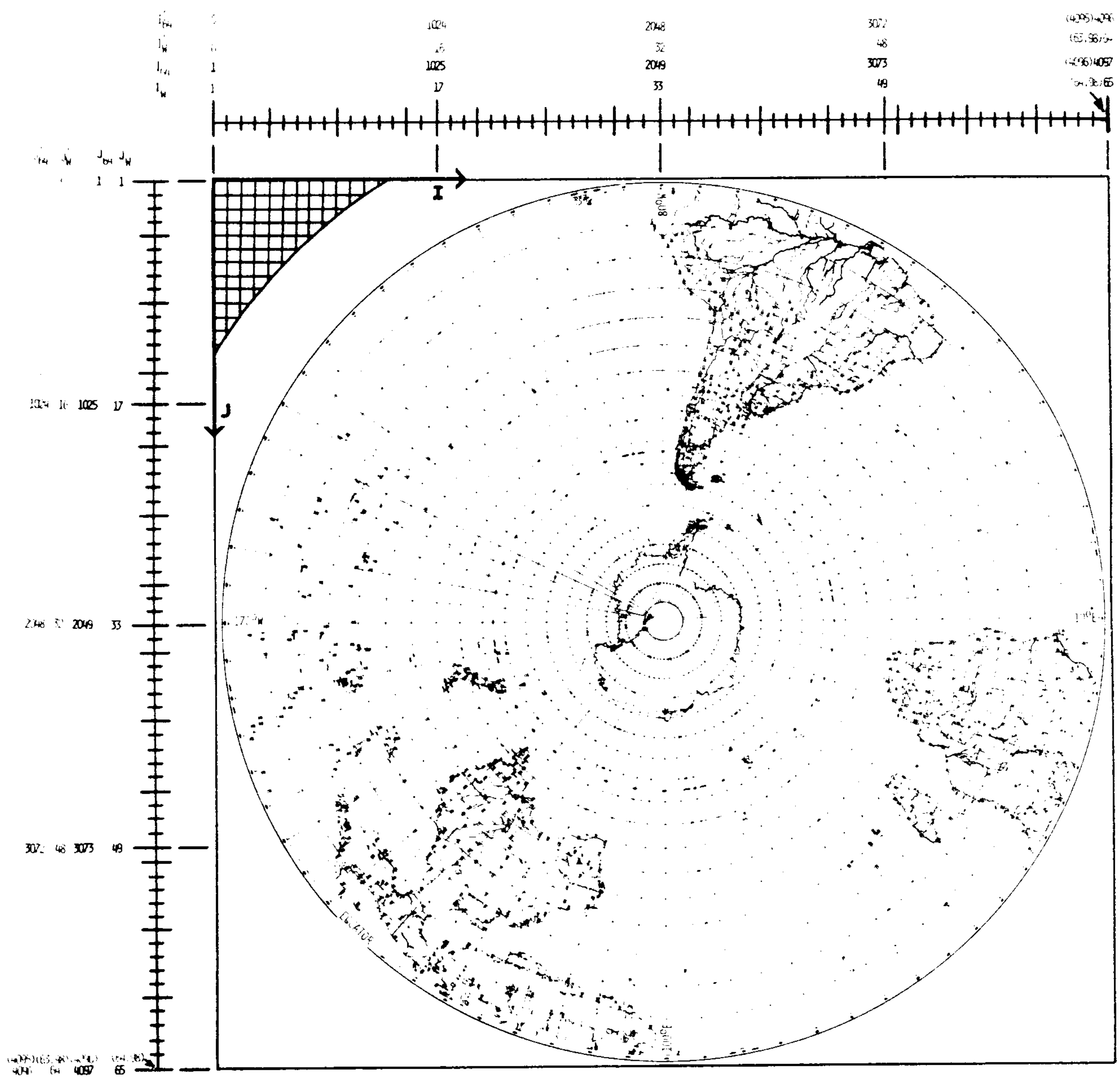


Figure 3.21. The grid system for the Satellite Global Data Base (SGDB) for the Southern Hemisphere. The (I,J) indexing convention is the same as that of the Sixty-fourth-mesh Reference Grid. The indices (I_w,J_w) and (I_{64},J_{64}) denote the coordinates of the Whole-mesh Reference Grid and the Sixty-fourth-mesh Reference Grid, respectively, whereas the indices (I_w',J_w') and (I_{64}',J_{64}') denote the numbering convention used in the satellite data processing software (SYNAPS). Examples of the 4096 SGDB boxes, which are one whole-mesh grid length on a side, are given in the upper-left corner of the domain. Imagery is not stored in those boxes that lie off the hemisphere. Each SGDB box contains the rows of grid points on the upper and left boundaries of the box, but <u>not</u> the lower and right boundaries. The index values in parentheses on the axes indicate the values of the last row of the SGDB grid system, which has one less row than the Sixty-fourth-mesh Reference Grid.

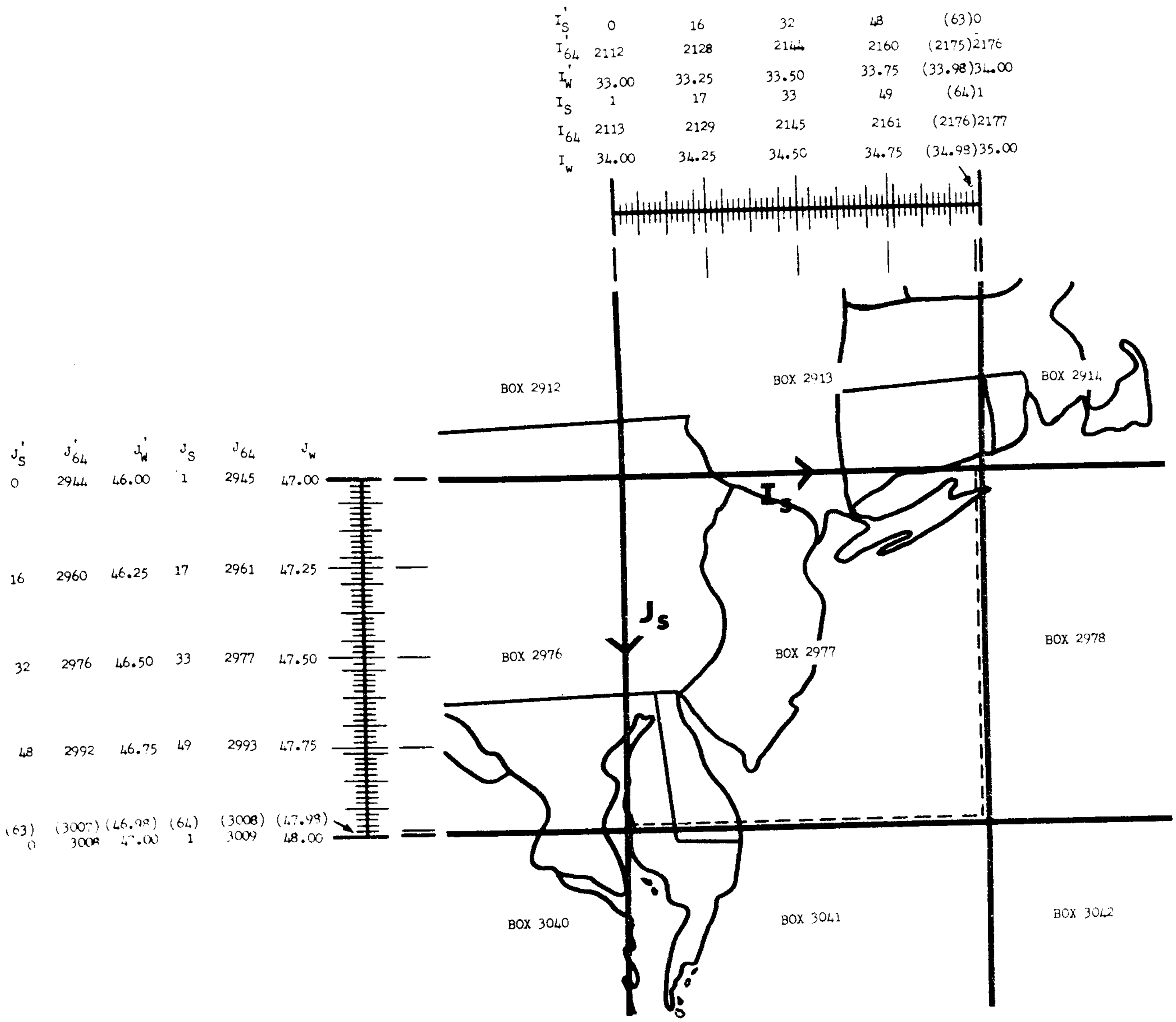


Figure 3.22. The relationship of SGDB Box IJ indices (I_s,J_s) to Whole-mesh Reference Grid indices (I_w,J_w) and Sixty-fourth-mesh Reference Grid indices (I_{64},J_{64}) for an example SGDB box (box number B_s = 2977). The indices (I_s',J_s'), (I_w',J_w'), and (I_{64}',J_{64}') denote the numbering convention used in the satellite data processing software (SYNAPS). Grid points on the lower and right boundaries (solid lines) of the box are located in adjacent boxes. The dashed lines indicate the actual lower and right boundary rows of the box, with (I,J) indices given in parentheses on the axes.

Satellite data processing software (SYNAPS) designates the origin of the Sixty-fourth-mesh Reference Grid as the point (0,0), as opposed to (1,1), the convention in this Technical Note. That is, with SYNAPS for the top row J = 0 and for the leftmost column I = 0. Consequently,

$$I'_w = I_w - 1 \quad , \tag{3.29}$$

$$J'_w = J_w - 1 \quad , \tag{3.30}$$

$$I'_{64} = I_{64} - 1 \; , \tag{3.31}$$

$$J'_{64} = J_{64} - 1 \; , \tag{3.32}$$

$$I'_s = I_s - 1 \quad , \tag{3.33}$$

$$J'_s = J_s - 1 \quad , \tag{3.34}$$

where (I_w', J_w'), (I_{64}', J_{64}'), and (I_s', J_s') are whole-mesh indices, sixty-fourth-mesh indices, and SGDB Box IJ indices, respectively, as used in SYNAPS.

Information stored on SGDB grids is not representative of conditions surrounding each grid point, as is the case for other AFGWC grids, such as the 3DNEPH grids. Instead, SGDB information stored at a Sixty-fourth-mesh Reference Grid Point (I_{64}, J_{64}) represents the conditions in the area bounded by that grid point and $(I_{64}+1, J_{64})$, $(I_{64}, J_{64}+1)$, and $(I_{64}+1, J_{64}+1)$.

3.1.3.6. STATIONARY WINDOW GRIDS.

Smaller-area subsets, or window grids, are also used in AFGWC models. These window grids include stationary windows for the North American, European, and Asian continents and movable windows of nearly constant areal extent. Each window is defined relative to a specific reference grid and obeys all conventions described for that reference grid. Table 3.6 details important parameters of each stationary window grid. Locations of the corner points with respect to the coordinates of the Whole-mesh Octagon were derived using eqs. (3.16) and (3.17) with (I,J) being the coordinates of the points with respect to each particular window grid, (I',J') the coordinates on the Whole-mesh Octagon, M = 1/2 for half-mesh grids, M' = 1 for the Whole-mesh Octagon, (I_p', J_p') = (47,51) from Table 3.5, and (I_p, J_p) from Table 3.6 for the respective stationary window grids.

3.1.3.6.1 STATIONARY WINDOW GRIDS FOR THE HALF-MESH ANALYSIS MODELS.

The three windows used for the Half-mesh Analysis Models are shown in Fig. 3.23 (solid lines) and summarized in Table 3.6. These grids are defined relative to the Half-mesh Reference Grid and include a 37x39 half-mesh window for North America and 35x41 half-mesh windows for the European and Asian areas. The (I,J) coordinate axes are as defined for the Half-mesh Reference Grid.

Table 3.6. Stationary Window Grids. The grid-point location of the pole is with respect to each particular stationary window grid, not the Reference Grids. (The pole is only within the domain of the European and Asian Half-mesh Analysis Model grids.) The mesh factor M for all these grids is 1/2. The (I,J) coordinates (on the whole-mesh octagon) of the corners of the window grids can be determined using other information in this table and eqs. (3.16) and (3.17).

DOMAIN	ARRAY SIZE IxJ = TOTAL NUMBER OF POINTS	GRID POINT LOCATION OF THE POLE (I_p,J_p)	(I,J) COORDINATES (OF THE WHOLE-MESH OCTAGON) FOR THE CORNERS OF THE WINDOW GRIDS			
			Corner Points			
			Upper Left	Upper Right	Lower Left	Lower Right
Stationary Window Grids for Half-mesh Analysis Models						
N. America	37x39 = 1443	(27,-3)	(11,28)	(29,28)	(11,47)	(29,47)
Europe	35x41 = 1435	(1,29)	(24,12)	(41,12)	(24,32)	(41,32)
Asia	35x41 = 1435	(25,41)	(12, 6)	(29, 6)	(12,26)	(29,26)
Boundary-layer Model Grids						
U.S.	29x27 = 783	(23,-13)	(13,33)	(27,33)	(13,46)	(27,46)
Europe	29x35 = 1015	(-3,27)	(26,13)	(40,13)	(26,30)	(40,30`
Asia	29x35 = 1015	(23,39)	(13, 7)	(27, 7)	(13,24)	(27,24

3.1.3.6.2 BOUNDARY-LAYER MODEL GRIDS.

The three windows used by the AFGWC Boundary-layer Model are also shown in Fig. 3.23 (inner dashed lines) and summarized in Table 3.6. A 29x27 half-mesh window for the U.S. and 29x35 half-mesh windows for Europe and Asia are defined.

3.1.3.7. MOVABLE WINDOW GRIDS

One set of movable window grids is used at AFGWC by the High-resolution Cloud Prognosis Model (HRCP). These grids are movable in the sense that some flexibility exists in specifying their location. Each window grid is one of the 3DNEPH boxes, discussed in Section 3.1.3.3, and contains an array of 64x64 eighth-mesh grid points. Fig. 3.17 provides an example of one such box (box number 44).

The particular 3DNEPH boxes are selected according to areas of interest and may be changed each time HRCP is used. Up to 12 boxes may be specified, although typically about 8 are selected. Forecasts for the boxes are made independently of each other by HRCP.

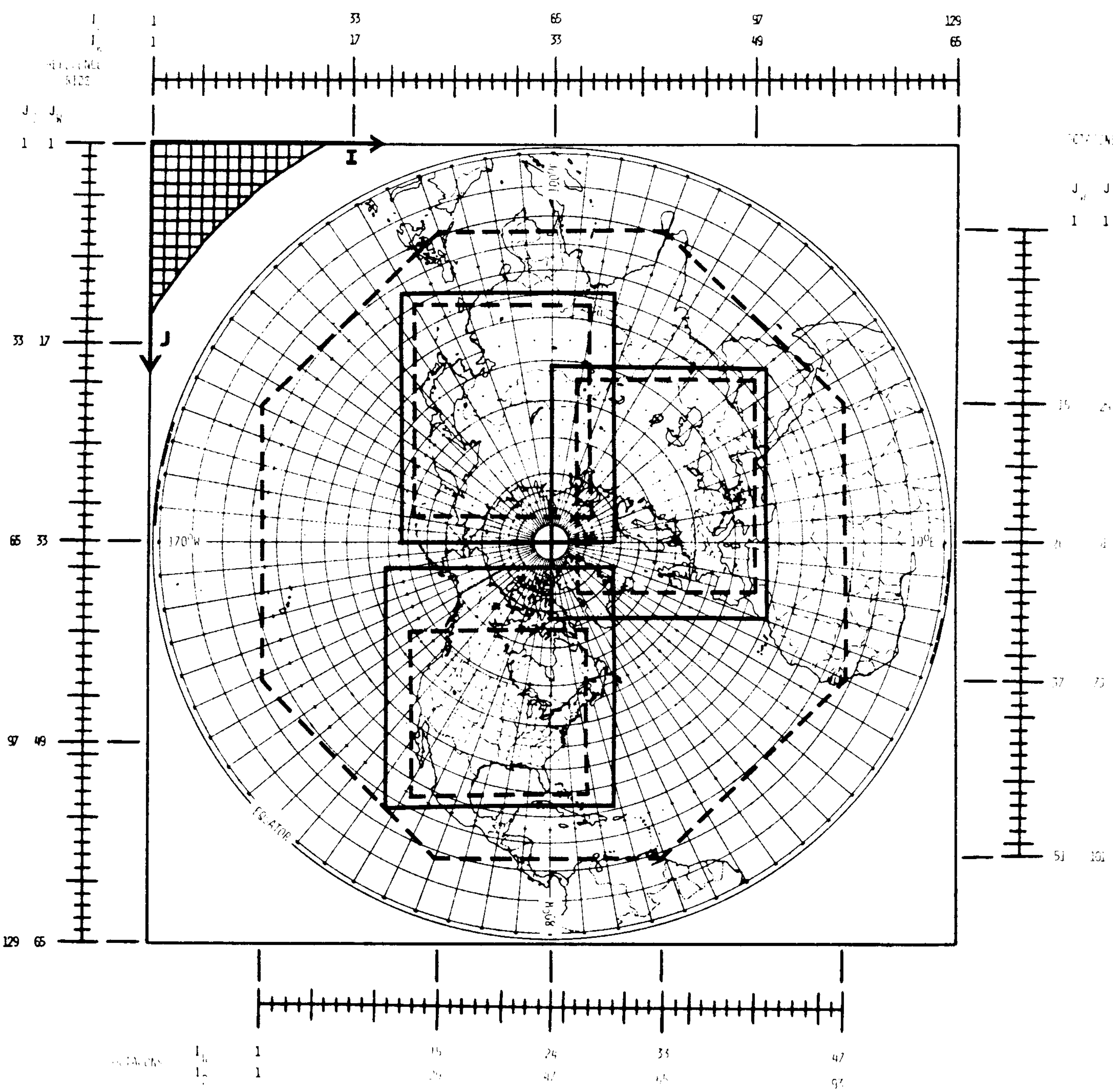


Figure 3.23. Half-mesh Analysis Model grids (solid lines) and Boundary-layer Model grids (inner dashed lines). The domain of the Northern Hemispheric Reference Grids (solid outer border) and the Northern Hemispheric Octagon grids (outer dashed lines) are indicated. The indices (I_w,J_w) and (I_2,J_2) designate the coordinates for the whole-mesh and half-mesh versions, respectively, with respect to the Octagons and the Reference Grids. The whole-mesh grid spacing is displayed in the upper-left corner.

3.2 MERCATOR GRIDS

Mercator grids are used at AFGWC for meteorological applications in tropical regions. There are two such grids. One we designate as the Conventional Tropical Grid (Fig 3.24), which is the grid used for the conventional meteorological elements, such as height, wind, and temperature. The second grid is the SGDB Tropical Grid (Fig. 3.25), which is used for processing satellite imagery. Both grids are on a Mercator projection true at 22.5°N and 22.5°S. The Conventional Tropical Grid is 73x19 with a grid length of 5° longitude, whereas the SGDB Whole-mesh Tropical Grid is 97x28 with a grid length of about 3.71° longitude. The Greenwich Meridian is represented by columns 1 and 73 in the former, but only by column 1 in the latter. If the SGDB Whole-mesh Tropical Grid had a 98th column, this column would be coincident with the Greenwich Meridian.

The longitudinal (east-west) spacing $\Delta\lambda$ between grid points is given by

$$\Delta\lambda = \begin{cases} 360^\circ/I_N & \text{, in degrees,} \\ 2\pi/I_N & \text{, in radians,} \end{cases} \tag{3.35}$$

where I_N is the number of nonduplicated points in the east-west direction. For the Conventional Tropical Grid $I_N = 72$, so that $\Delta\lambda = 5° = 0.087266$ radians longitude. Because $I_N = 97$ for the SGDB Tropical Grid, $\Delta\lambda$ is about 3.7113° or 0.064775 radians longitude.

The distance d_i between grid points on the image plane for a Mercator projection is given by

$$d_i = a\ (\cos\phi_1)\ \Delta\lambda \quad , \tag{3.36}$$

where a is the earth's radius, ϕ_1 is a standard latitude (22.5°N at AFGWC), and $\Delta\lambda$ is the longitudinal spacing in radians calculated from eq. (3.35). As mentioned above for the Conventional Tropical Grid, the spacing is 5° = 0.087266 radians longitude, so that according to eq. (3.36), for $\phi_1 = 22.5°N$, we obtain $d_i = 513.67...$ km. For the SGDB Whole-mesh Tropical Grid, $\Delta\lambda$ is about 3.7113° = 0.064775 radians, so that $d_i = 381.28...$ km.

The distance d_e between grid points on the earth's surface can be derived from d_i by applying the definition of image scale σ (Section 2.2) to eq. (3.36):

$$d_e = \frac{d_i}{\sigma} = a\ (\cos\phi)\ \Delta\lambda \quad , \tag{3.37}$$

where σ is specified by eq. (2.9) using standard latitude ϕ_1 of 22.5°N, ϕ is latitude, and $\Delta\lambda$ is the longitudinal spacing in radians (see preceding paragraph). The variation of distance d_e between grid points is shown as a function of latitude in Fig. 3.26. Because the grid length d_e for the whole-mesh polar stereographic grids and for the SGDB Whole-mesh Tropical Grid are approximately equal, the latter is designated the whole-mesh grid length for Mercator projections.

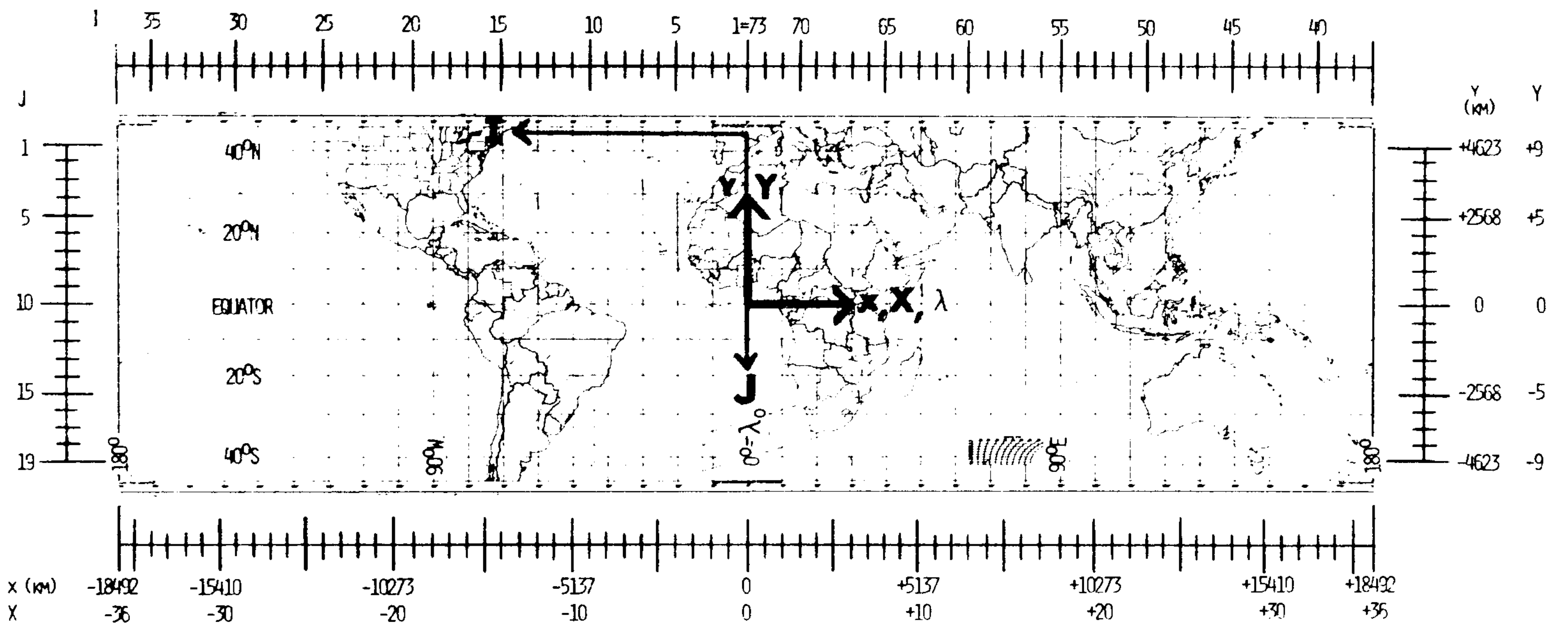


Figure 3.24. The Conventional Tropical Grid. Included are the axes for the (I,J) indexing convention, the image-plane Cartesian coordinates (x,y), and the grid-point Cartesian coordinates (X,Y). Longitude is designated by λ and reference longitude by λ_0. (At AFGWC, $\lambda_0 = 0^\circ$.) Only one of several possible labeling conventions for the x and X axes is included (see eqs. (2.10) and (3.39)). The distances for the (x,y) coordinates are, by definition, with respect to the image plane.

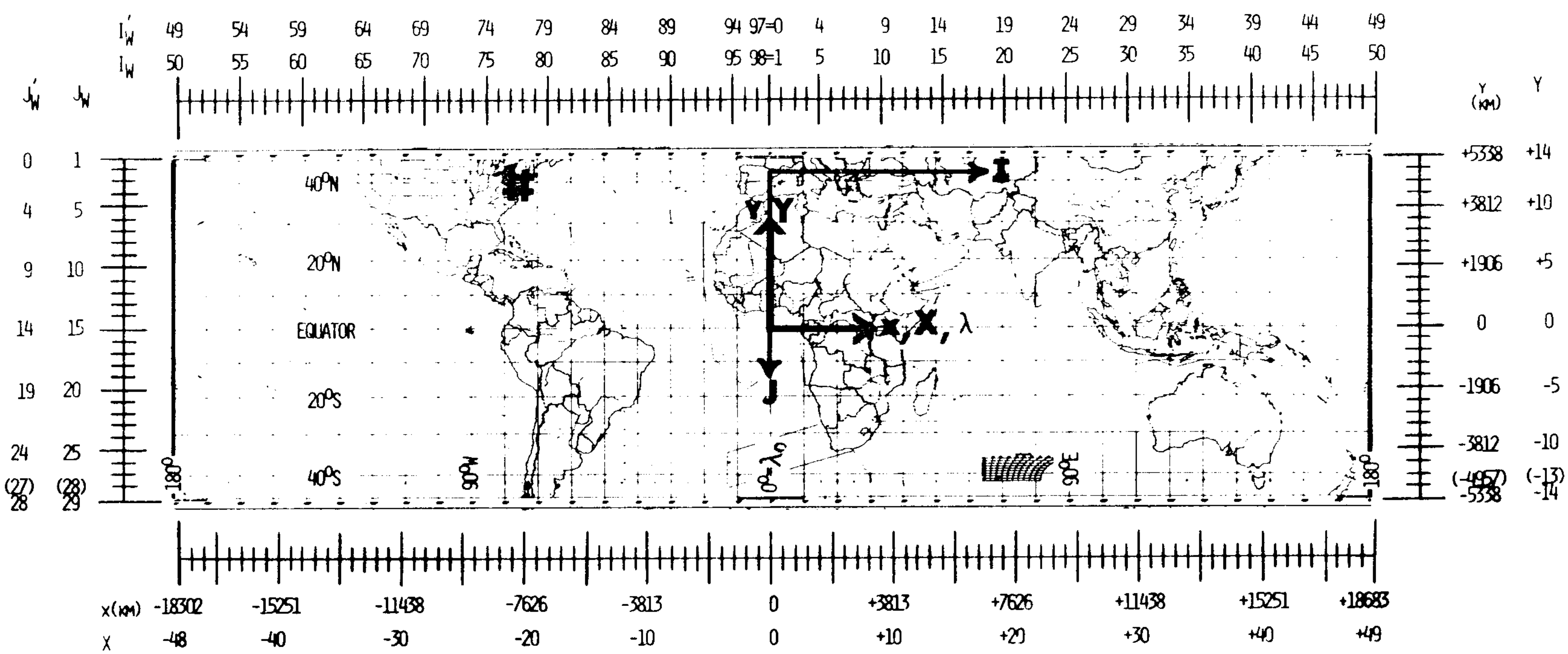


Figure 3.25. The SGDB Tropical Grid. Included are the axes for the (I,J) indexing convention, the image-plane Cartesian coordinates (x,y), and the grid-point Cartesian coordinates (X,Y). Longitude is designated by λ and reference longitude by λ_0. (At AFGWC, $\lambda_0 = 0°$.) Only one of several possible labeling conventions for the x and X axes is included (see eqs. (2.10) and (3.39)). The distances for the (x,y) coordinates are, by definition, with respect to the image plane. The indices (I_W, J_W) denote the coordinates of the SGDB Tropical Whole-mesh Grid. The indices (I_W', J_W') denote the numbering convention used in the satellite data processing software (SYNAPS). Over the U.S., box number $B_s = 270$ is given as an example. Each SGDB box contains the rows of grid points on the upper and left boundaries of the box, but <u>not</u> the lower and right boundaries. The values in parentheses on the axes indicate the values of the actual last row of the SGDB Whole-mesh Tropical Grid.

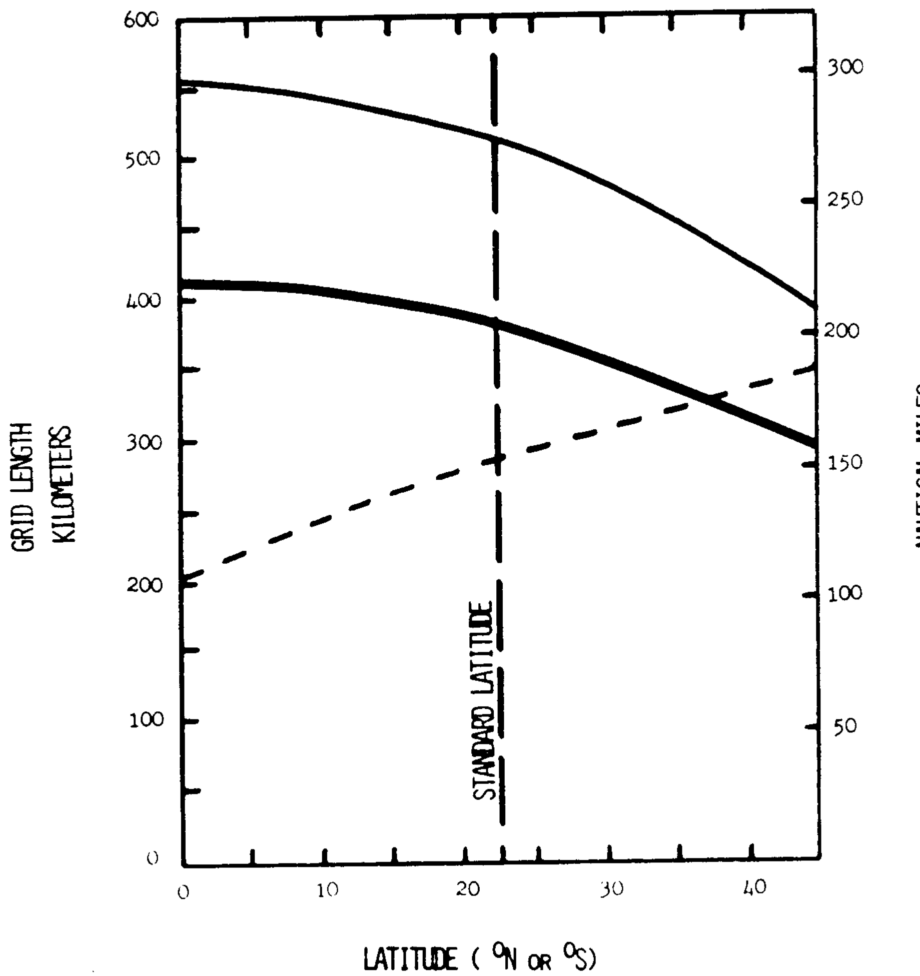


Figure 3.26. The grid length d_e on the earth's surface as a function of latitude for 1) the Conventional Tropical Grid (upper solid curve) with standard latitudes of 22.5°N and 22.5°S, 2) the SGDB Whole-mesh Tropical Grid (lower solid curve) with standard latitudes of 22.5°N and 22.5°S, and 3) a whole-mesh grid on a polar stereographic projection (short-dashed curve) (see Fig 3.5). The long-dashed vertical line indicates the standard latitude of 22.5°N or °S.

Because the grid length d_e is a function of latitude, the distance d_e' between grid points on the earth's surface in the north-south direction is not quite equal to d_e. Instead, we have that

$$d_e' = a\ \Delta\phi \quad , \tag{3.38}$$

where $\Delta\phi$ is the latitudinal spacing (in radians) between adjacent grid points. As stated above, the distance d_e between adjacent grid points along a given latitude corresponds to 5° longitude for the Conventional Tropical Grid. By equating d_e and d_e' in eqs. (3.37) and (3.38), we can show that distance d_e' between adjacent grid points along a meridian corresponds to about 5° latitude at the Equator and about 3.8° latitude near the northern and southern boundaries. Similarly, for the SGDB Whole-mesh Tropical Grid, for which d_e corresponds to about 3.7° longitude, d_e' corresponds to about 3.7° latitude at the Equator and about 2.6° latitude near the northern and southern boundaries.

The (I,J) indexing conventions for the two grids are shown in Figs.3.24 and 3.25. The convention for the Conventional Tropical Grid is right-handed; that is, I increases from right to left (east to west) and J increases from top to bottom (north to south). The convention for the SGDB Whole-mesh Tropical Grid, however, is left-handed: I increases from west to east and J increases from north to south.

Grid-point Cartesian coordinate systems (X,Y) are defined for both tropical Mercator grids. The system is right-handed for both (Figs. 3.24 and 3.25). The origin for both systems is located at the intersection of the Equator and the Greenwich Meridian. Equations for (X,Y) in multiples of distance d_i between grid points on the image plane are

$$X = G\ (I - 1 + KI_N) \quad , \quad 1 \le I \le I_M \quad , \tag{3.39}$$

$$Y = -\ (J - J_E) \quad , \quad 1 \le J \le J_M \quad . \tag{3.40}$$

In these equations K is any integer, although usually 0 or -1. J_E is the J coordinate of the Equator. I_M is the total number of points in the east-west direction. I_N is the number of nonduplicated points in the east-west direction, with point I = 1 being coincident with point I_N+1. J_M is the number of points in the north-south direction. Finally, G designates the grid, with G = -1 for the Conventional Tropical Grid and G = +1 for the SGDB Whole-mesh Tropical Grid. Table 3.7 contains a summary of the values of these parameters for the two Mercator grids.

Table 3.7. Parameters for the Mercator Grids.

PARAMETER	SYMBOL	CONVENTIONAL TROPICAL GRID	SGDB WHOLE-MESH TROPICAL GRID
Standard latitudes	ϕ_1, ϕ_2	22.5°N, 22.5°S	22.5°N, 22.5°S
Reference longitude	λ_o	0°E	0°E
Longitudinal grid spacing	$\Delta\lambda$	5° longitude	3.7113° longitude
Distance between grid points on the image plane	d_i	513.67 km	381.28 km
(I,J) axes		right-handed	left-handed
(X,Y) axes		right-handed	right-handed
Total number of points in the east-west direction	I_M	73	97
Number of nonduplicated points in the east-west direction	I_N	72	97
Number of points in the north-south direction	J_M	19	28
Range of I index		$1 \leq I \leq I_M$ $1 \leq I \leq I_N+1$	$1 \leq I \leq I_M$ $1 \leq I \leq I_N$
Range of J index		$1 \leq J \leq J_M$	$1 \leq J \leq J_M$
J coordinate of the Equator	J_E	10	15
Grid designator	G	-1	+1

Image-plane Cartesian coordinates (x,y) can be calculated from (X,Y) coordinates by multiplying each (X,Y) value by d_i (the image-plane distance between grid points):

$$x = d_i\, X \quad , \tag{3.41}$$

$$y = d_i\, Y \quad . \tag{3.42}$$

Using eqs. (2.10), (2.11), (3.36), and (3.39)-(3.42), we can derive the latitude ϕ and longitude λ of any grid point from its (I,J) coordinates:

$$\phi = 2 \arctan \left\{ \exp \left[\frac{\pi}{180^{\circ}} (\Delta\lambda)(J_E - J) \right] \right\} - 90^{\circ} \quad , \tag{3.43}$$

$$\lambda = \begin{cases} G(I-1)(\Delta\lambda) + \lambda_o & , \\ G(I-I_N-1)(\Delta\lambda) + \lambda_o & , \end{cases} \tag{3.44}$$

where the various parameters are provided in Table 3.7. In eq. (3.43) note that $\Delta\lambda$ and the functional value of the arctangent should be in degrees.

The (I,J) coordinates of any point within the latitudinal bounds of the tropical grids may be calculated from latitude and longitude (eqs. (3.43) and (3.44)) according to

$$I = \begin{cases} 1 + \left(\dfrac{\lambda - \lambda_o}{\Delta\lambda} \right) & , \text{ SGDB Whole-mesh Tropical Grid} , \\ \\ I_N + 1 - \left(\dfrac{\lambda - \lambda_o}{\Delta\lambda} \right) & , \text{ Conventional Tropical Grid} , \end{cases} \tag{3.45}$$

$$J = J_E - \left(\frac{180^{\circ}}{\pi(\Delta\lambda)} \right) \ln[\tan \tfrac{1}{2}(\phi + 90^{\circ})] \quad . \tag{3.46}$$

In eq. (3.45) λ must have a range of $\lambda_o \leq \lambda < \lambda_o + 360^{\circ}$ for the SGDB Whole-mesh Tropical Grid and $\lambda_o \leq \lambda \leq \lambda_o + 360^{\circ}$ for the Conventional Tropical Grid.

3.2.1 Conventional Tropical Grid

The Conventional Tropical Grid is formed by superimposing a 73x19 array of points on a Mercator projection such that row 10 ($J = 10$) coincides with the Equator and columns 1 ($I = 1$) and 73 ($I = 73$) both coincide with the Greenwich Meridian. As shown in Fig. 3.24, the grid extends completely around the world longitudinally and includes that portion of the globe between approximately 41°N and 41°S. This grid is one of the few at AFGWC to use a right-handed (I,J) indexing convention. Equations governing this grid are presented in the preceding section, with the relevant grid parameters specified in Table 3.7.

The grid-point Cartesian coordinate system (X,Y) provides the frame of reference for orientation of wind components: the u component is positive in the direction of decreasing X and the v component is positive in the direction of decreasing Y (Fig. 3.24).

3.2.2. SGDB Tropical Grid System

The SGDB Whole-mesh Tropical Grid is formed by superimposing a 97x28 array of points on a Mercator projection such that row 15 ($J = 15$) coincides with the Equator and column 1 coincides with the Greenwich Meridian. If a 98th column were included, it would also coincide with the Greenwich Meridian. As shown in Fig. 3.25 the grid extends completely around the world longitudinally and from about 46°N to 46°S latitudinally. Equations governing this grid are presented in Section 3.2, with the relevant grid parameters specified in Table 3.7.

As was similarly true for SGDB grids on polar stereographic projections, the SGDB Whole-mesh Tropical Grid is partitioned into boxes to facilitate processing of satellite data. Each SGDB box contains one grid point (I_w,J_w) of the SGDB Whole-mesh Tropical Grid and consists of a 64x64 array of sixty-fourth-mesh points. There are 97x28 = 2716 boxes containing a total of 11,124,736 grid points. Each point (I_w,J_w) coincides with the sixty-fourth-mesh point in the upper-left corner of the SGDB box. SGDB boxes are numbered according to

$$B_s = (I_w-1) + 97(J_w-1) \quad , \quad \begin{cases} 1 \le I_w \le 97 & , \\ 1 \le J_w \le 28 & , \end{cases} \tag{3.47}$$

where (I_w,J_w) are the indices for the SGDB Whole-mesh Tropical Grid of the point at the upper-left corner of the box and B_s is the SGDB box number. Note that $0 \le B_s \le 2715$.

Satellite data processing software (SYNAPS) designates the origin of the SGDB Whole-mesh Tropical Grid as the point (0,0), as opposed to (1,1), the convention of this Technical Note. Consequently,

$$I'_w = I_w - 1 \quad , \tag{3.48}$$

$$J'_w = J_w - 1 \quad , \tag{3.49}$$

where (I_w', J_w') are the whole-mesh indices as used in SYNAPS.

3.3 LATITUDE-LONGITUDE GRID

The Global Applications Data Base (GADB) grid is the only latitude-longitude grid currently in use at AFGWC. It consists of a 73x52 array of points extending around the world in a band between 87.5°N and 87.5°S. This grid is formed by allowing each point to represent a specific latitude and longitude (Fig. 3.27). For example, grid point (1,1), in the upper-left corner of the grid, represents 2.5°E/87.5°N. Grid spacing is 5° longitude in the east-west direction; this longitudinal spacing is the same as the Conventional Tropical Grid. In the north-south direction, spacing is 2.5° latitude in the region 17.5°N to 57.5°N and 17.5°S to 57.5°S, and 5° latitude elsewhere.

For this grid the (I,J) indexing convention is left-handed; that is, the I index increases from left to right (west to east) as J increases from top to bottom (north to south). Columns I = 1 and I = 73 represent the same longitude, 2.5°E, with the Greenwich Meridian being centered between columns I = 72 and I = 73. The Equator lies midway between rows J = 26 and J = 27.

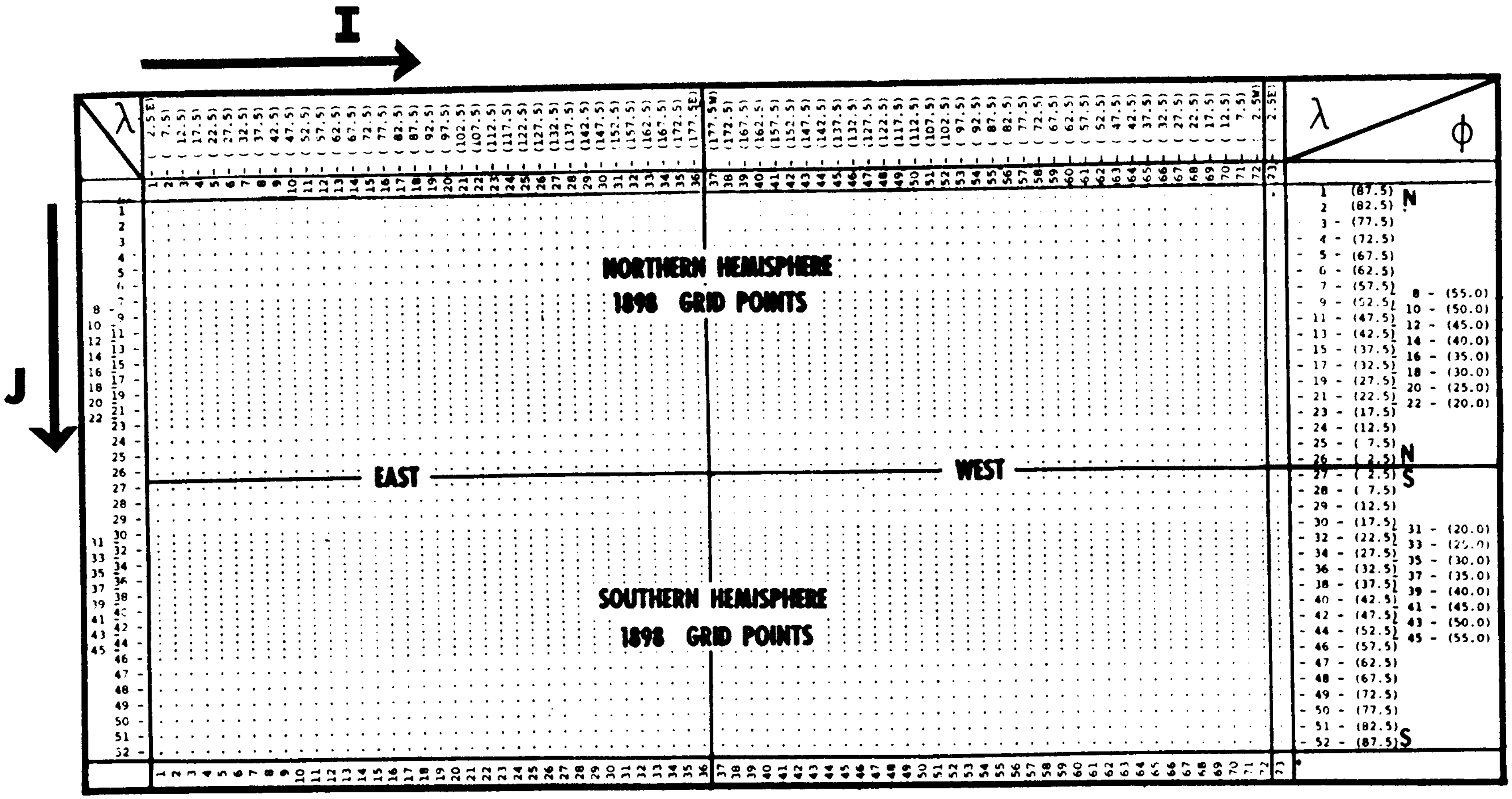


Figure 3.27. The grid of the Global Applications Data Base (GADB). Included are the axes for the (I,J) indexing convention and the corresponding latitudes ϕ and longitudes λ.

SECTION 4. APPENDIX A--THE REGIONS OF THE AFGWC REGIONS DATA BASE

World-wide observations from land surface stations and radiosondes, for example, are often located geographically by the WMO according to WMO Regions. Figs. A.1 and A.2 indicate the WMO Regions for the Northern and Southern Hemispheres, respectively. Because these regions are occasionally modified, an up-to-date, authoritative reference should be consulted when knowledge of exact regions is important.

At AFGWC, these observations are not stored at grid points but rather are stored individually by geographic regions in the so-called Regions Data Base. Fig. A.3 shows the domains of the 65 Northern Hemispheric regions and Fig. A.4 the domains for the 11 Southern Hemispheric regions.

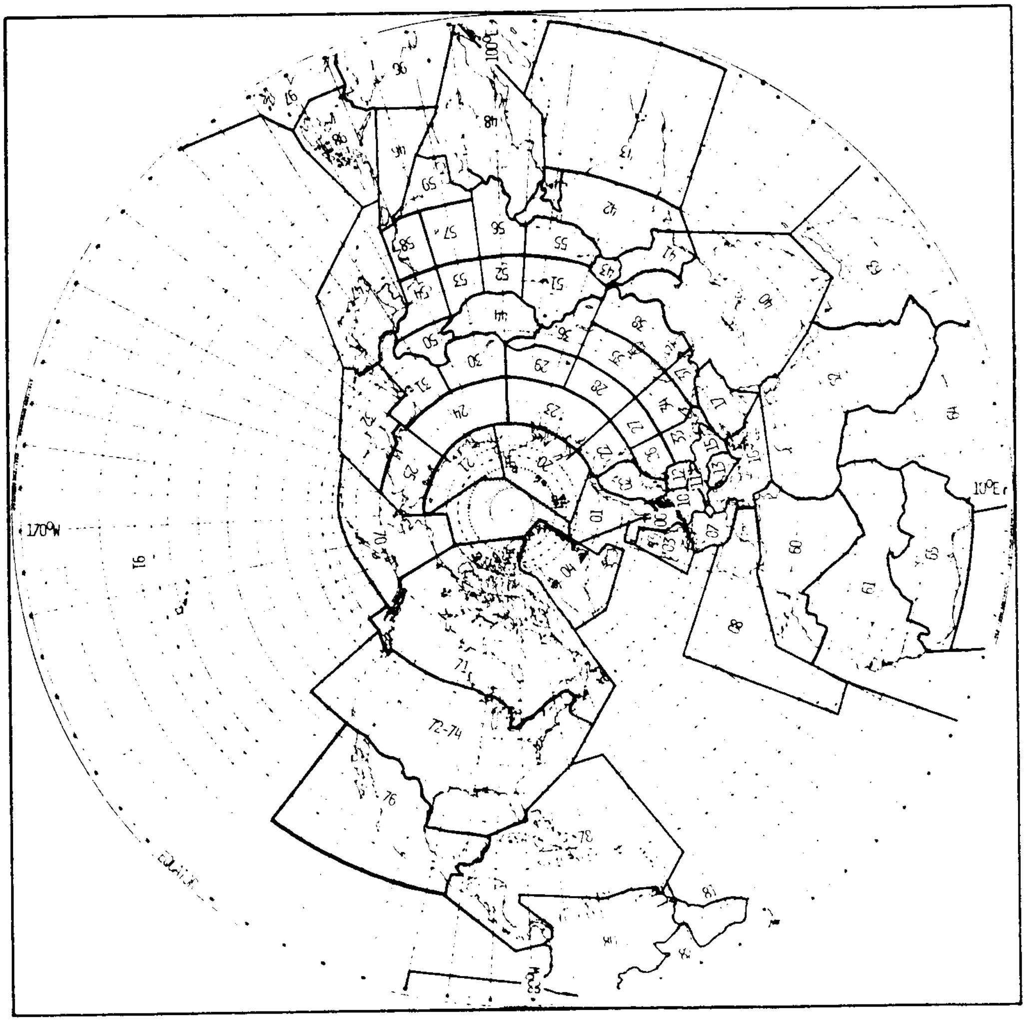


Figure A.1. World Meteorological Organization Regions for locating meteorological observations in the Northern Hemisphere. The domain of the Northern Hemispheric Reference grids is indicated by the solid outer border.

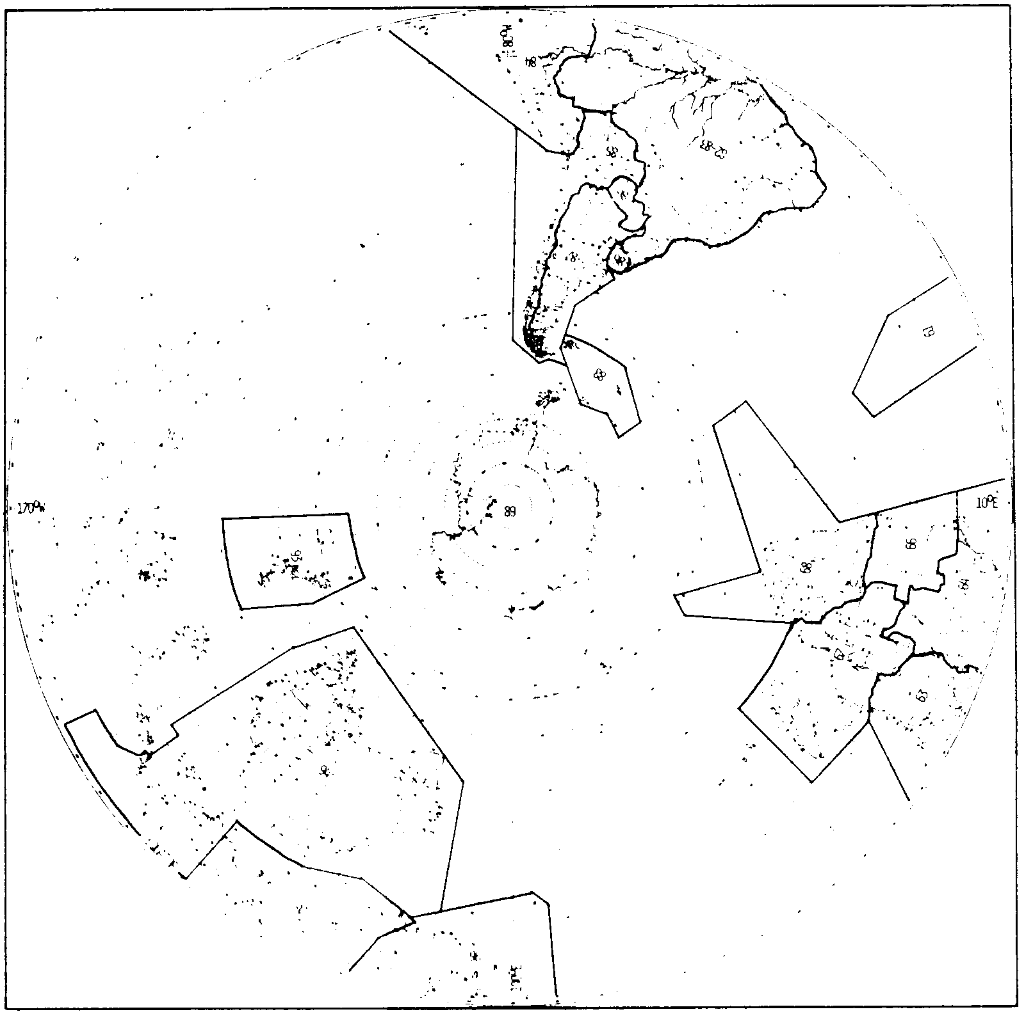


Figure A.2. World Meteorological Organization Regions for locating meteorological observations in the Southern Hemisphere. The domain of the Southern Hemispheric Reference grids is indicated by the solid outer border.

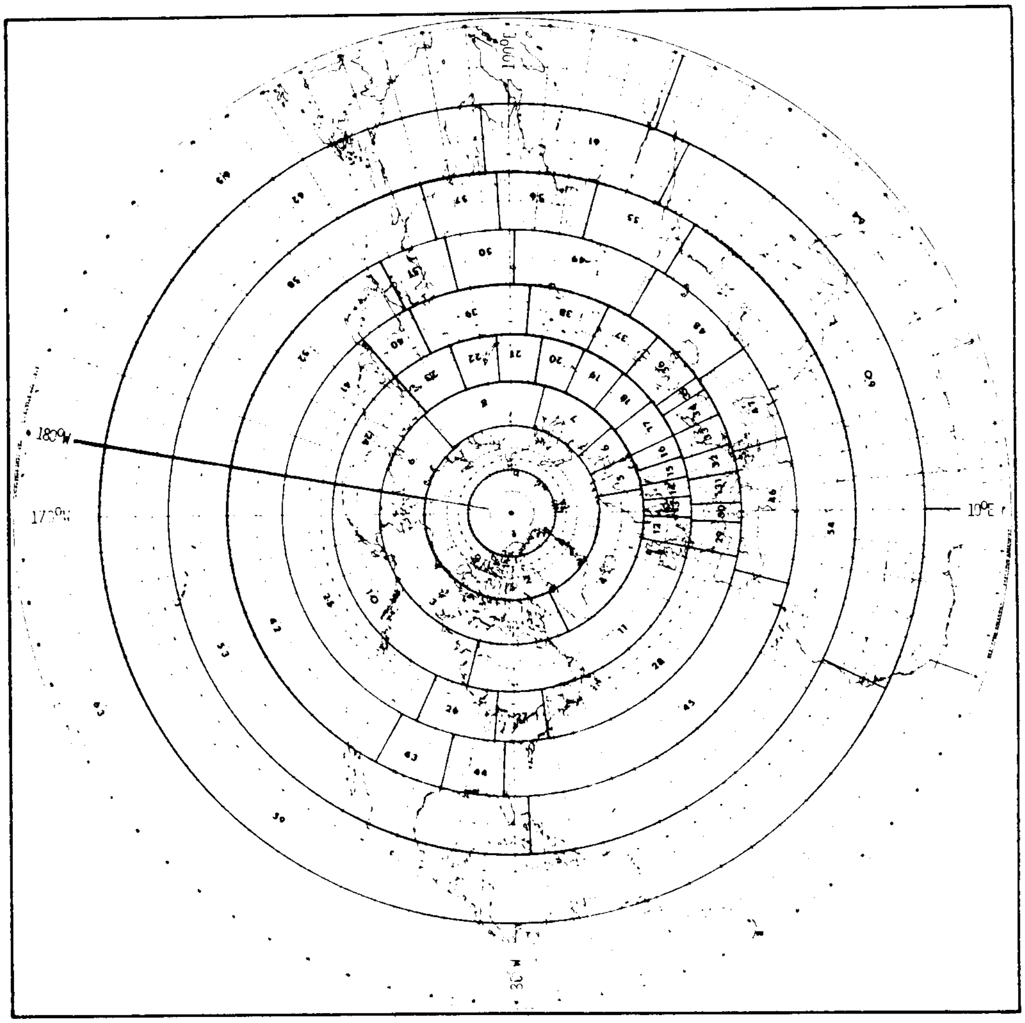


Figure A.3. AFGWC Northern Hemispheric Regions for storing observations in the Regions Data Base. There are 65 Northern Hemispheric Regions, numbered from 1 to 65. The domain of the Northern Hemispheric Reference Grids is indicated by the solid outer border.

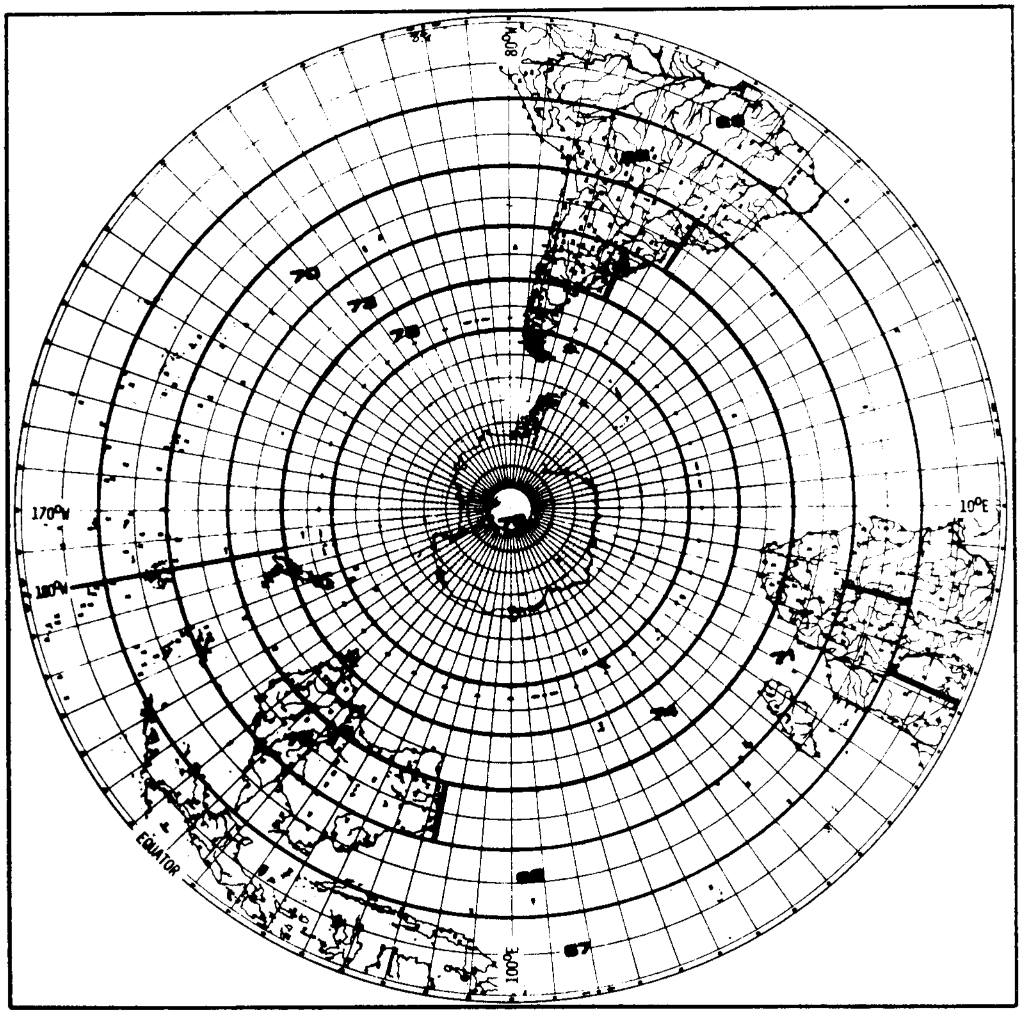


Figure A.4. AFGWC Southern Hemispheric Regions for storing observations in the Regions Data Base. There are 11 Southern Hemispheric Regions, numbered from 66 to 76. The domain of the Southern Hemispheric Reference Grids is indicated by the solid outer border.

SECTION 5. APPENDIX B--GLOSSARY

This is an alphabetical listing of definitions and acronyms used in this Technical Note. A List of Symbols is presented elsewhere. Location of additional information or primary usage is indicated, when appropriate.

AFGWC	- Air Force Global Weather Central.
AGL	- Above ground level.
Analysis	- Process in which data are interpolated from the observational points to the grid points (Section 3).
Asian boundary-layer window	- Areal subset of the Asian window; used by the Asian Boundary-layer Model (Section 3.1.3.6.2).
Asian window	- Stationary window covering eastern Asia; used by the Asian Half-mesh Analysis Models (Section 3.1.3.6.1).
AWSPE	- Air Weather Service Primitive Equation Model; primary whole-mesh forecast model for the Northern Hemisphere; provides forecasts from the earth's surface to 100 mb (Section 3.1.3.2).
Bedient	- Same as whole-mesh grid length (Section 3.1.1).
Boundary-layer Model	- Model that provides half-mesh forecasts for eight levels from the earth's surface to 1600 m AGL; used with the Asian, European, and U.S. boundary-layer windows (Section 3.1.3.6.2).
Class	- One of five different categories by which projections can be grouped. The classes are not mutually exclusive (Section 2.3).
Coincidence class	- Indicates the type of contact between the earth and the geometric figure associated with a projection (Section 2.3).
Conformal variety	- A variety of the property class in which the angles between intersecting curves and, therefore, the shapes of small features on the earth's surface are maintained. A differentially small distance on the projection will correspond to a distance on the earth's surface independent of direction from a point (Section 2.3).
Conical variety	- A variety of the nature class in which a cone is the geometric figure associated with the projection (Section 2.3).
Constant of the cone (n)	- A scaling factor used in Lambert conformal projections (see Section 2.6.2, eq. (2.13)).

Conventional Tropical Grid - A tropical grid on a Mercator projection used for the conventional meteorological elements, such as height, wind, and temperature (Section 3.2).

Conventional variety - A variety of the generation class in which the projection is derived from the earth's surface mathematically, without using rays (Section 2.3).

Cylindrical variety - A variety of the nature class in which a cylinder is the geometric figure associated with the projection (Section 2.3).

Developing - The process of cutting and unfolding a three-dimensional surface to produce a planar surface (Section 2.2).

Domain - The horizontal area represented by, for example, a map or grid.

Eighth-mesh grid - Grid on which the grid length is one-eighth the whole-mesh value.

Equidistant variety - A variety of the property class in which distances between points on the earth are correctly represented on the projection (Section 2.3).

Equivalent variety - A variety of the property class in which areas of features on the earth are correctly represented on the projection (Section 2.3).

European boundary-layer window - Areal subset of the European window; used by the European Boundary-layer Model (Section 3.1.3.6.2).

European window - Stationary window covering Europe and western Asia; used by the North American Half-mesh Analysis Models (Section 3.1.3.6.1).

Finer-mesh grid - Grid with a grid length shorter than the whole-mesh grid length (Section 3).

GADB - Global Applications Data Base; data base containing global analyses and forecasts of various meteorological elements used primarily in computer flight planning (Section 3.3).

Generation class - Indicates the method used to construct the image surface in generating a projection (Section 2.3).

Geometric variety - A variety of the generation class in which the surface of the earth is simply projected using rays onto a geometric figure in generating a projection (Section 2.3).

Geometric figure - Two- or three-dimensional surface associated with a projection of the earth's surface (Section 2.2).

Great circle	- A line of shortest length between two points along the earth's surface (Section 2.6.1).
Grid	- Array of points used to represent locations on the surface of the earth (Section 3).
Grid increment	- Same as grid length.
Grid interval	- Same as grid length.
Grid length	- Distance between adjacent points on a grid.
Grid-point Cartesian coordinates (X,Y)	- A Cartesian coordinate system for a grid in which locations are specified by multiples of the grid length for that particular grid on the image plane.
Grid unit	- Same as grid length.
Half-mesh grid	- Grid on which the grid length is one-half the whole-mesh value.
Half-mesh Analysis Model	- Numerical weather analysis model which uses a half-mesh grid.
HRCP	- High-resolution Cloud Prognosis Model; cloud forecast model with fifteen levels in the vertical and eighth-mesh horizontal resolution (Section 3.1.3.7).
HUFANL	- Hough Global Spectral Analysis Model; provides whole-mesh global analyses for the mandatory pressure levels from the earth's surface to 100 mb.
IJ indexing convention	- System for uniquely identifying individual grid points.
Image plane	- The two-dimensional surface to which the surface of the earth is transformed by projection, by pure mathematical equations, or by a combination of both; a planar image surface or an image surface that has been developed into a plane (Section 2.2).
Image-plane Cartesian coordinates (x,y)	- A Cartesian coordinate system that is on the image plane and is independent of grid length.
Image-plane polar coordinates (r,θ)	- A polar coordinate system on the image plane.
Image scale (σ)	- Ratio, at a point, of differential distance on an image surface or image plane to differential distance on the surface of the earth (Section 2.2).
Image surface	- The surface (not necessarily two-dimensional) to which the surface of the earth is transformed by projection, by pure mathematical equations, or by a combination of both (Section 2.2).

INT	- Mathematical function whose functional value is the integer portion of the division of the first argument by the second argument; for example, INT(10,3) = 3 (Section 3.1.3.3).
Lambert conformal projection	- One type of conformal projection using a cone as the image surface; common in limited-area midlatitudinal applications (Section 2.6).
Longitudinal grid spacing	- Spacing of grid points in the east-west direction.
Loxodrome	- Line or path that maintains fixed compass direction; shown on a map as a line crossing all meridians at the same angle; also called rhumb line (Section 2.5.1).
Map	- Two-dimensional horizontal representation of the surface of the earth with size convenient for display, analysis, and interpretation of information (Section 2.2).
Map factor (m)	- Ratio, at a point, of differential distance on a map to differential distance on the earth; the product of image scale σ and map scale μ (Section 2.2).
Map scale (μ)	- Ratio of distance on a map to distance on the image surface or image plane; describes mathematically the uniform reduction from image surface or image plane to map surface (Section 2.2).
Mercator projection	- One type of conformal projection using the cylinder as the image surface; common in tropical applications (Section 2.5).
Meridian	- Line of constant longitude, extending from the North Pole to the South Pole.
Mesh factor (M)	- Ratio of the grid length to the whole-mesh grid length on the image plane (Section 3.1.1).
Mesh size	- Indicator of the relative grid length for a particular grid (for example, whole mesh, half mesh, eighth mesh) (Section 3.1.2.4).
MOD	- Mathematical function in which the functional value is the remainder of the division of the first argument by the second argument; for example, MOD(10,3) = 1 (Section 3.1.3.3).
Movable window grid	- Grid with a limited-area domain whose location can be varied (Section 3.1.3.7).
Nature class	- Indicates the geometric figure associated with a projection (Section 2.3).

NH	- Northern Hemisphere (Table 3.5).
Normal variety	- A variety of the position class in which the axis of symmetry of the geometric figure associated with the projection coincides with the rotational axis of the earth (Section 2.3).
North American window	- Stationary window covering most of North America; used by the North American Half-mesh Analysis Models (Section 3.1.3.6.1).
Oblique variety	- A variety of the position class in which the axis of symmetry of the geometric figure associated with the projection is neither perpendicular to nor coincident with the rotational axis of the earth (Section 2.3).
Octagon	- Same as Octagon Grid.
Octagon grid	- An octagon-shaped grid; an important numerical weather analyses and prediction grid for both the Northern and Southern Hemispheres (Section 3.1.3.1).
Orthomorphic variety	- Same as conformal variety.
Parallel	- Line of constant latitude, encircling the earth in the east-west direction.
Perspective variety	- Same as geometric variety.
Planar	- Pertaining to a plane; two-dimensional.
Planar variety	- A variety of the nature class in which a plane is the geometric figure associated with the projection (Section 2.3).
Polar stereographic projection	- One type of conformal projection using a plane as the image surface; common in Northern and Southern Hemispheric applications (Section 2.4).
Polysuperficial variety	- A variety of the coincidence class in which a succession of different geometric figures is associated with the projection (Section 2.3).
Position class	- Indicates the alignment of the axis of the earth with respect to the geometric figure associated with a projection (Section 2.3).
Projection	- The representation of the surface of the earth on an image surface or image plane. In some cases this representation can be generated geometrically using rays from a point on or within the earth's surface to project the earth's surface onto a geometric figure (Section 2.2).

Property class	- Indicates the conservation of distance, area, shape, or angle in generating a projection (Section 2.3).
Quarter-mesh grid	- Grid on which the grid length is one-fourth the whole-mesh value.
Ray	- Straight line used to project the surface of the earth onto the geometric figure.
Reference grid	- The areal superset grid for all grids of a given mesh size and hemisphere.
Reference longitude	- Longitude used in specifying the coordinate axes for projections, maps, and grids.
Regions Data Base	- AFGWC data base in which observations are stored individually by geographic regions (Section 4).
Rhumb line	- Same as loxodrome.
Secant variety	- A variety of the coincidence class in which the geometric figure associated with the projection intersects the earth's interior (Section 2.3).
Semi-geometric	- A variety of the generation class in which the projection is derived from the earth's surface using a combination of projection by rays and mathematics without consideration of rays (Section 2.3).
SGDB	- Satellite Global Data Base; data base that contains global high-resolution (about 3 nm or 6 km) radiance measurements (from satellite) in the visual and infrared ranges (Sections 3.1.3.5, 3.2).
SGDB box	- Areal subset of the SGDB grid; each box contains 64x64 = 4096 sixty-fourth-mesh points (Sections 3.1.3.5, 3.2.2).
SGDB Box IJ convention	- Convention for uniquely specifying each of the 64x64 grid points in a SGDB box (Section 3.1.3.5).
SGDB Box IJ indices	- The indices of the SGDB Box IJ convention (Section 3.1.3.5).
SGDB Tropical Grid	- A tropical grid on a Mercator projection used for processing satellite imagery (Section 2.3).
SH	- Southern Hemisphere (Table 3.5.).
SIXLVL	- Six-level Baroclinic Prediction Model; provides operational forecasts for the Southern Hemisphere and updated forecasts for the Northern Hemisphere (Section 3.1.3.2).
Sixty-fourth-mesh grid	- Grid on which the grid length is one-sixty-fourth the whole-mesh value.

Standard latitude(s)	- Latitude(s) at which the image surface represents true earth distance; that is, latitude(s) at which the image scale σ is unity.
Stationary window grid	- Grid with a limited-area domain whose location cannot be varied (Section 3.1.3.6).
Super Grid	- Same as Reference Grid.
SYNAPS	- Program that processes video and infrared satellite data and stores them into the SGDB; the processing interface between the satellite data formaters and the SGDB. The name is derived from the word synapse, which is the point of contact along which impulses are transmitted between two nerve cells (Sections 3.1.3.5, 3.2.2).
Tangent variety	- A variety of the coincidence class in which the geometric figure associated with the projection intersects only the earth's surface and not the earth's interior (Section 2.3).
Transverse variety	- A variety of the position class in which the axis of symmetry of the geometric figure associated with the projection is perpendicular to the rotational axis of the earth (Section 2.3).
TRONEW	- Tropical Cloud Forecast Model (Section 3.1.3.4).
True latitude	- Same as standard latitude.
U.S. boundary-layer window	- Areal subset of the North American window; used by the U.S. Boundary-layer Model (Section 3.1.3.6.2).
U.S. window	- Same as North American window.
Variety	- One of the mutually exclusive subsets of each of the five classes used in categorizing projections (Section 2.3).
Whole-mesh grid	- Grid whose grid length serves as a basis for all finer-mesh grid lengths; grid whose grid length is the whole-mesh grid length (Sections 3.1.1, 3.2).
Whole-mesh grid length	- For a polar stereographic projection, a grid length of exactly 381 km at 60°N (or °S) on the earth's surface; for a Mercator projection, a grid length of approximately 381 km at 22.5°N and °S on the earth's surface (Sections 3.1.1, 3.2).
Whole-mesh grid spacing	- Same as whole-mesh grid length.
WMO	- World Meteorological Organization.

WMO Region	- A geographic region by which the location of observations may be specified according to convention established by the WMO (Section 4).
3DNEPH	- Three-dimensional Nephanalysis Model; provides eighth-mesh cloud analyses for both the Northern and Southern Hemispheres (Section 3.1.3.3).
3DNEPH box	- One of 64 areal subsets of the 3DNEPH grid; each box contains 64x64 = 4096 eighth-mesh points (Section 3.1.3.3).
3DNEPH Box IJ convention	- Convention for uniquely specifying each of the 64x64 grid points in a 3DNEPH box (Section 3.1.3.3).
3DNEPH Box IJ indices	- The indices of the 3DNEPH Box IJ convention (Section 3.1.3.3).

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Addendum to AFGWC Technical Note 79/003 (Revised), "Map Projections and Grid Systems for Meteorological Applications"

1. This addendum to AFGWC/TN-79/003 (Rev) defines the new AFGWC sixteenth-mesh grid system defines the sixteenth-mesh grid in relation to other AFGWC grid systems. It consists of changes to existing tables in the current Technical Note and additional equations defining the sixteenth-mesh grid. The new sixteenth-mesh grid is defined both in "super I,J" coordinates and in relation to the current eight-mesh grid box system.

2. Page 37. Replace current Table 3.3 with:

Table 3.3 The Polar Stereographic Reference Grids.

MESH SIZE	MESH FACTOR (M)	ARRAY SIZE IxJ = TOTAL NUMBER OF POINTS		GRID POINT LOCATION OF THE POLE (I_p, J_p)	DISTANCE d_e BETWEEN GRID POINTS AT 60° LATITUDE (N/S) KILOMETERS	NAUTICAL MILES*
WHOLE	1	65x65=	4,225	(33, 33)	381.	205.72354
HALF	1/2	129x129=	16,641	(65, 65)	190.5	102.86177
QUARTER	1/4	257x257=	66,049	(129, 129)	95.25	51.43088
EIGHTH	1/8	513x513=	263,169	(257, 257)	47.625	25.71544
SIXTEENTH	1/16	1025x1025=	1,050,625	(513, 513)	23.8125	12.85772
THIRTY-SECOND	1/32	2049x2049=	4,198,401	(1025, 1025)	11.90625	6.42886
SIXTY-FOURTH	1/64	4097x4097=	16,785,409	(2049, 2049)	5.953125	3.21443

* based on the international nautical mile (nm) for which 1 nm = 1852 m.

3. Page 42. Replace current Table 3.5 with:

Table 3.5. Hemispheric Grids for Numerical Weather Analysis and Forecasting. The pole location is with respect to each particular grid, not the Reference Grids. NH indicates Northern hemisphere (H = +1, $_o$ = 60°N) and SH indicates Southern Hemisphere (H = -1, $_o$ = 60°S).

GRID	DOMAIN	MESH FACTOR (M)	ARRAY SIZE IXJ = TOTAL NUMBER OF POINTS		GRID POINT LOCATION OF THE POLE (I_p, J_p)
Whole-mesh Octagon	NH/SH	1	47X51 =	2,397	(24, 26)
Half-mesh Octagon	NH/SH	1/2	93X101 =	9,393	(47, 51)
TRONEW	NH/SH	1/2	128X128 =	16,384	(65, 65)
AWSPE	NH only	1	53X57 =	3,021	(27, 29)
SIXLVL	NH/SH	1	51x51 =	2,601	(26, 26)
3DNEPH	NH/SH	1/8	512x512 =	262,144	(257, 257)
Sixteenth-mesh	NH/SH	1/16	1024x1024 =	1,048,576	(513, 513)
SGDB	NH/SH	1/64	4096x4096 =	16,777,216	(2049, 2049)

3. Page 51, add the following:

"3.1.3.3.a. SIXTEENTH-MESH GRIDS

Sixteenth-mesh grids are 1024x1024 subsets of the 1025x1025 Sixteenth-mesh Reference Grids. The bottom row (J=1025) and the right-most column (I=1025) are not included in the hemispheric subset grids to be used by sixteenth-mesh gridded models (Figs 3.15 and 3.16). Information stored on sixteenth-mesh grids is assumed to be representative of conditions surrounding each grid point.

Sixteenth-mesh hemispheric grids can be partitioned into the same 64 3DNEPH boxes as eighth-mesh hemispheric grids, so as to facilitate processing and adaption into the current AFGWC software architecture. As in 3DNEPH processing, the four corner boxes will not be used. Each box, though, will contain an 128x128 array of sixteenth-mesh grid points. Within the Sixteenth-mesh Reference Grid, the 3DNEPH box number (B_n) for any particular eighth-mesh 3DNEPH box is given by:

$$B_n = 1 + \mathrm{INT}(I_{16}-1,\ 128) + 8[\mathrm{INT}(J_{16}-1,\ 128)] \qquad (3.18a)$$

for $1 \leq I_{16} \leq 1024$ and $1 \leq J_{16} \leq 1024$. The INT and MOD functional designators are the same as described above in para 3.1.3.3.

Within each box, an indexing convention (I_n, J_n) is used to designate the 128x128 array of grid points (see Fig. 3.17). Sixteenth-mesh Reference Grid indices (I_{16}, J_{16}) can be obtained from the sixteenth-mesh indices (I_n, J_n) in any 3DNEPH box (B_n) by:

$$I_{16} = I_n + 128[\mathrm{MOD}(B_n-1,\ 8)] \qquad (3.19a)$$

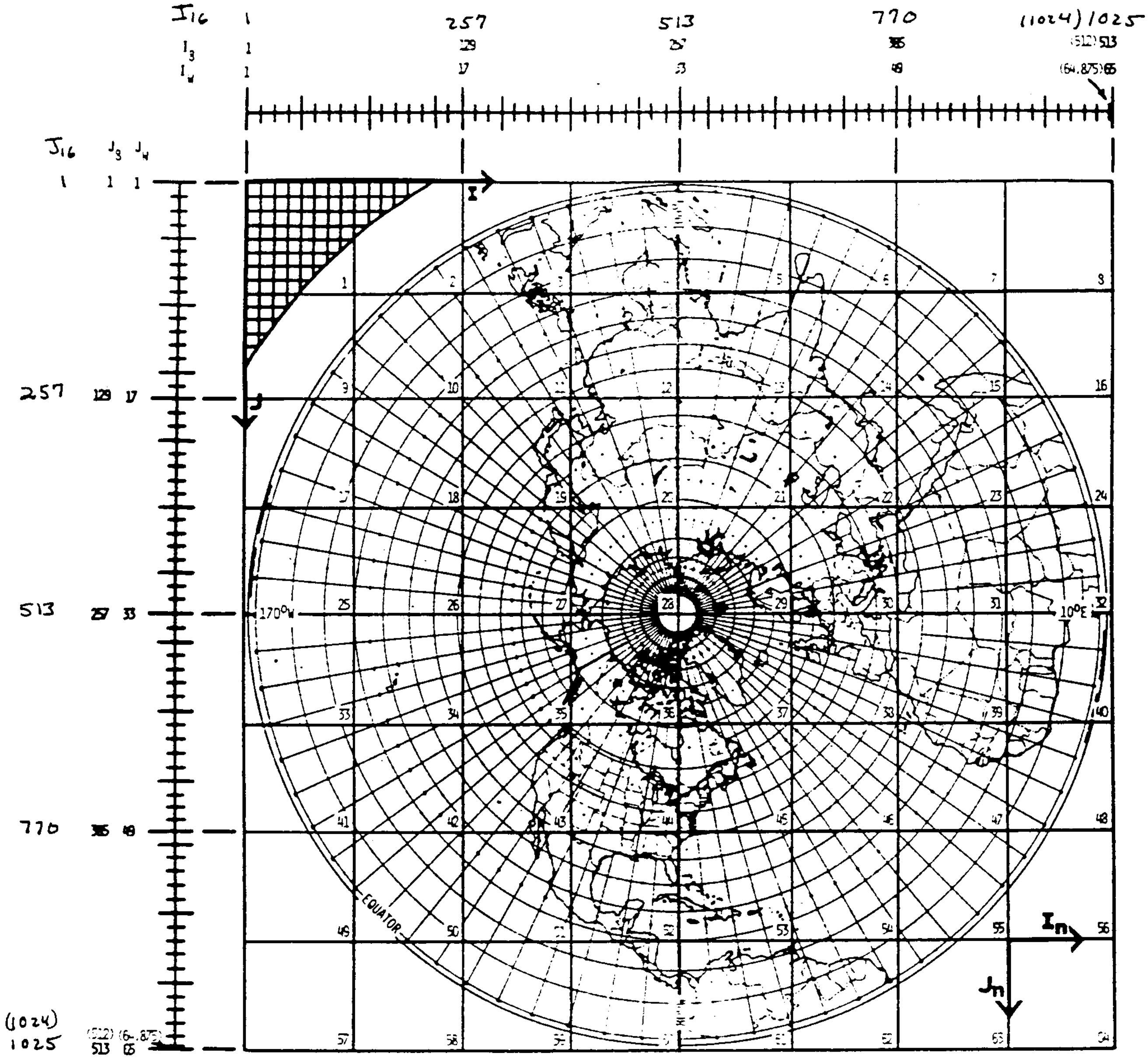
$$J_{16} = J_n + 128[\mathrm{INT}(B_n-1,\ 8)] \qquad (3.20a)$$

where $1 \leq I_n \leq 128$ and $1 \leq J_n \leq 128$.

Sixteenth-mesh Reference Grid indices (I_{16}, J_{16}) may be transformed to sixteenth-mesh indices (I_n, J_n) internal to any particular 3DNEPH Box by:

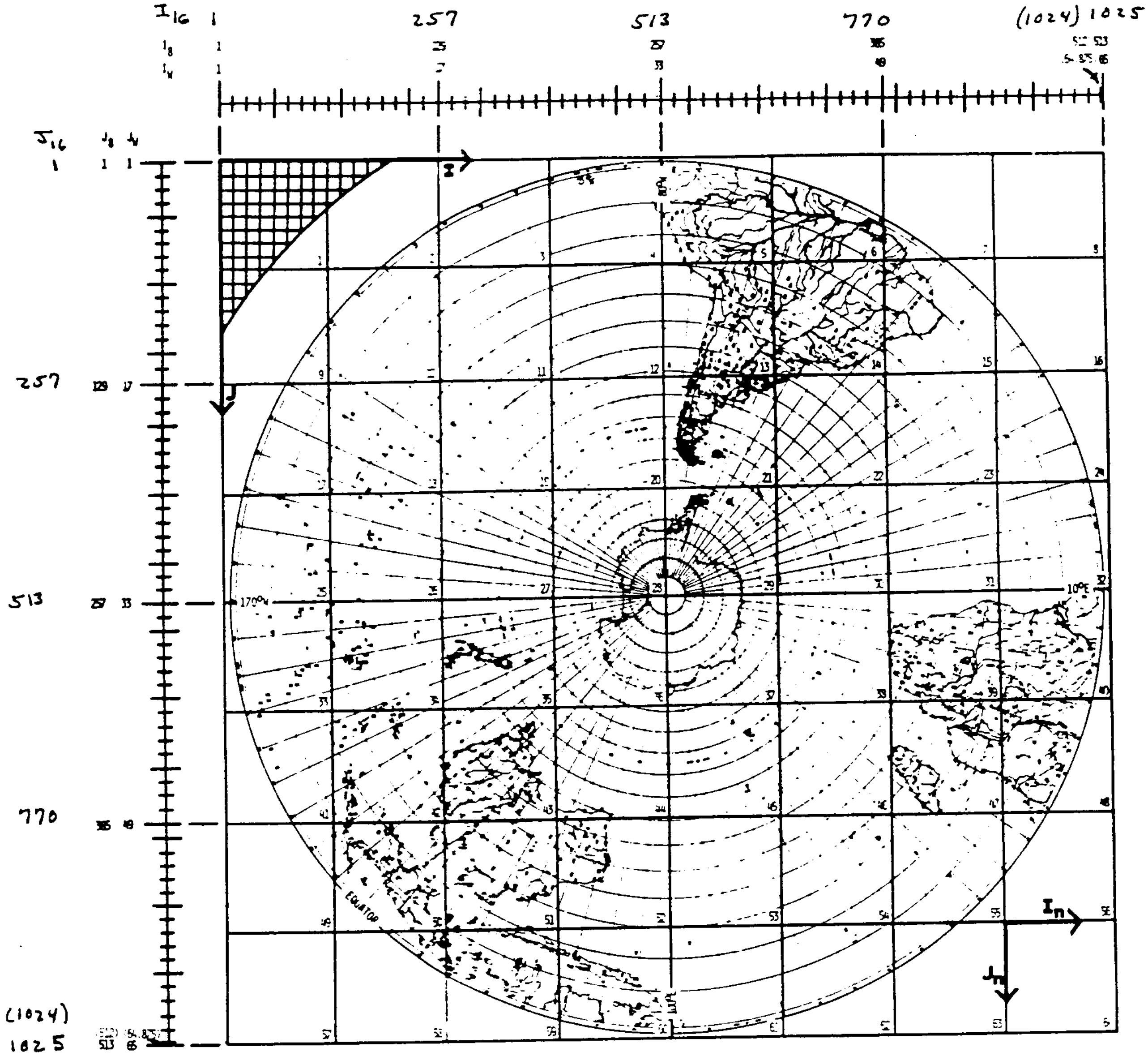
$$I_n = 1 + \mathrm{MOD}(I_{16}-1,\ 128) \qquad (3.21a)$$

$$J_n = 1 + \mathrm{MOD}(J_{16}-1,\ 128) \qquad (3.22a)"$$



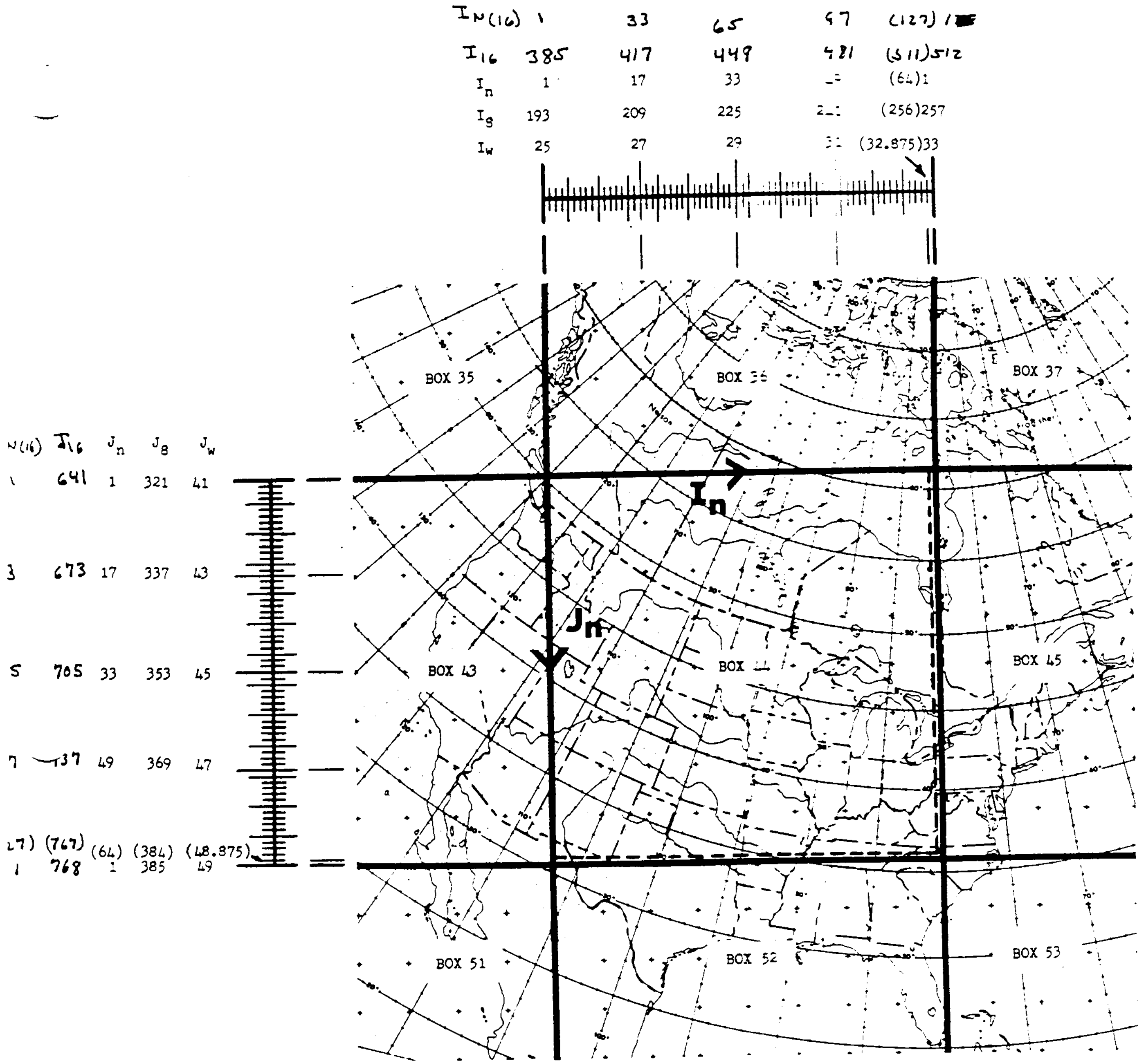
4. Page 49. Replace Figure 3.15 as attached. Replace caption with:

"The grid system of the Real-time Nephanalysis (RTNEPH) and Sixteenth-mesh gridded models for the Northern Hemisphere. The (I, J) indexing conventions are the same as those for the Eighth-mesh and Sixteenth-mesh Reference Grids. The indices (I_W, J_W), (I_8, J_8) and (I_{16}, J_{16}) denote the whole-mesh, eighth-mesh, and sixteenth-mesh coordinates, respectively, for the Reference Grids, RTNEPH, and sixteenth-mesh models. The 64 RTNEPH boxes are indicated; the four corner boxes are not used. The (I_n, J_n) coordinate axes in the lower-right corner show the RTNEPH Box IJ convention for a sample RTNEPH box. Each RTNEPH box contains the grid points on the upper and left boundaries, but not the lower and right boundaries. The labels (64.875), (512), and (1024) on the axes respectively indicate the whole-mesh, eighth-mesh, and sixteenth-mesh values of the last row of the RTNEPH and sixteenth-mesh model grid systems, which each have one less row than the Eighth-mesh and Sixteenth-mesh Reference Grids. The whole-mesh grid spacing is displayed in the upper-left corner."



5. Page 50. Replace Figure 3.16 as attached. Replace caption with:

"The grid system of the Real-time Nephanalysis (RTNEPH) and Sixteenth-mesh gridded models for the Southern Hemisphere. The (I, J) indexing conventions are the same as those for the Eighth-mesh and Sixteenth-mesh Reference Grids. The indices (I_w, J_w), (I_8, J_8) and (I_{16}, J_{16}) denote the whole-mesh, eighth-mesh, and sixteenth-mesh coordinates, respectively, for the Reference Grids, RTNEPH, and sixteenth-mesh models.
The 64 RTNEPH boxes are indicated; the four corner boxes are not used. The (I_n, J_n) coordinate axes in the lower-right corner show the RTNEPH Box IJ convention for a sample RTNEPH box. Each RTNEPH box contains the grid points on the upper and left boundaries, but not the lower and right boundaries. The labels (64.875), (512), and (1024) on the axes respectively indicate the whole-mesh, eighth-mesh, and sixteenth-mesh values of the last row of the RTNEPH and sixteenth-mesh model grid systems, which each have one less row than the Eighth-mesh and Sixteenth-mesh Reference Grids. The whole-mesh grid spacing is displayed in the upper-left corner."



6. Page 52. Replace Figure 3.17 as attached. Replace caption with:

"The relationship of RTNEPH Box IJ indices (I_n, J_n) to Whole-mesh Reference Grid indices (I_w, J_w), Eighth-mesh Reference Grid indices (I_8, J_8), and Sixteenth-mesh Reference Grid indices (I_{16}, J_{16}) for an example RTNEPH box (box number B_n=44). Note that grid points on the lower and right boundaries (solid lines) of the box are located in adjacent boxes. The dashed lines indicate the actual lower and right boundary rows of the box, with (I, J) indices given in parentheses on the axes."